Limerick Clare Energy Plan

Climate Change Strategy

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Limerick Clare Energy Plan: Climate Change Strategy

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Executive Summary

The Limerick-Clare Region (LCR) has a long history of innovation within the energy sector in Ireland, which includes the construction of Ireland's largest hydro plant, Ardnacrusha, in the late 1920's as well as Ireland's largest power plant, Moneypoint, in the 1980's. Currently, energy systems worldwide are facing a new challenge, to transition to low-carbon sustainable forms of energy and therefore, the LCR has the opportunity to become a leading innovator within the energy sector once again. This study investigates how the LCR can begin the transition to a sustainable energy system by outlining some key actions between now and 2020. Furthermore, a long-term vision is also presented to illustrate how these actions contribute to the final objective of a low-carbon 100% renewable energy system.

Key Conclusions

- **More renewable energy is possible in the LCR by 2020, while also reducing energy costs and creating 2,000 more local jobs.**
  By 2020, the LCR can produce 70% of its electricity and 25% of its total energy demands from renewable energy if the 'LCR 2020' scenario in this study is implemented. Furthermore, this can be done while also reducing the cost of energy, reducing greenhouse gas emissions, reducing the demand for energy, and also creating approximately 2,000 local jobs within the region.

- **Particular focus should be placed on the heating sector in the LCR between now and 2020.**
  There are well-established technologies which can be implemented immediately in the LCR. The primary solutions that should be implemented are district heating in the urban areas and individual heat pumps in the rural areas. For the electricity and transport sectors, actions outlined by the Irish government should be implemented.

- **District heating is a cheaper alternative than natural gas for individual urban buildings.**
  District heating is explicitly discussed in this report since it is not a well-established technology in Ireland. As part of this discussion, district heating is compared to natural gas since the gas network is already well-established in the region. The results verify that district heating is a cheaper alternative which will also generate more jobs for the local economy (since it is an investment-based solution unlike natural gas which is a fuel-based solution).

- **A 100% renewable energy system will offer significant benefits for the local citizens of the LCR.**
  This includes approximately more local jobs, less pollution, new skills and new business opportunities. Results indicate that if the LCR achieves a 100% renewable energy system by 2050, it will be cheaper than a fossil fuel alternative if fuel prices continue as forecasted. The impact of the balance of payment for the region is also positive, going from a net loss based on importing fuel to a net gain based on local investments. Therefore, renewable energy should not be viewed as something that the region needs to do, but instead as something that can be done to improve local society.

- **It is important to ensure that the demand for biomass in a 100% renewable energy system does not exceed the resource available.**
  In line with this, it is important to quantify the residual resource available and subsequently develop different biomass resource scenarios for the future: this can inform the debate surrounding the amount of biomass that will be available for a 100% renewable energy system. In addition, industry currently consumes a very large proportion of the biomass in the 100% renewable scenarios created in this study (~35-40%). Therefore, a study should be carried out identifying how much of the industry demand can be converted to either district heating or electricity, so more abundant renewable resources can be used instead of biomass.

Key Recommendations

- **Actions towards a 100% renewable energy system can begin today.**
  Numerous technologies which are recommended in this study between now and 2020 are already commercially available today. These include energy efficiency, the installation of wind turbines, heat pumps in rural houses, district heating in urban buildings, and the expansion of electric vehicles and public transport.

- **The LCR has a unique motivation and opportunity to develop and brand itself as a 100% renewable energy region.**
  Firstly, the LCR can build a very positive brand for the region associated with innovation, sustainability, and community collaboration. Secondly, with the Limerick regeneration project currently underway, there is an opportunity to develop an energy exemplar project such as a low-temperature district heating network. Thirdly, recent statistics indicated that “at administrative county level Limerick City

had the highest unemployment rate in 2011" [1], so creating 2,000 more local jobs based on the actions outlined in this report should be of particular interest to the LCR.

- **The local authorities in the LCR can play a key role in the transition to a sustainable energy system using very long-term (i.e. ownership and operation of infrastructure) or short-term (i.e. facilitating and networking) methods.**
  For example, a simple start is to bring the key energy stakeholders together to develop an energy steering group for the region, which is made up of key decision makers, local authority members, local politicians, and community groups. Initial meetings should be used to assess the appetite for developing the Limerick-Clare region as a 100% renewable region (or whatever the target may be), as it will only be possible with the support, involvement, and collaboration between all sectors of the community. If this goal is to be fulfilled, resources will then need to be allocated from all parties to create a management team to run the project, including expertise, time, and financial support. A detailed description of the working group required to run such a project is available from both SEAI [2] and the IEA [3]. Other initial steps could be an energy efficiency network connecting consumers with reliable tradesmen or quantifying the energy demand in the region in more detail (i.e. using audits or heat atlases), so other organisations can also create energy alternatives in the region.

- **National government policies must allow for socio-economic alternatives to be implemented at local level.**
  Like any local planning authority, clear support from central government is a key advantage when implementing local initiatives. However, under current policies, subsidies, and taxes, the most socio-economic alternatives identified in this study may not be the most business-economic alternatives. Therefore, it is important that the Irish government structure their policies so that the most socio-economic alternatives are implemented at a local level. For example, this may require a subsidy for heat pumps in rural homes. An existing policy which illustrates this is the new REFIT of €100-150/MWh in Ireland to support approximately 50 MW of CHP based on anaerobic digestion [4, 5]. This could be utilised in the Limerick Clare region to support the expansion of district heating. From the results in this study, it is not possible to identify how policies will need to be reorganised to support the scenario recommended, but during the implementation phase this will become apparent and so national policy support will be essential.

Key Messages

- **This study is only a snapshot in time of how the energy system in the Limerick-Clare Region could evolve.**
  Naturally, knowledge will continuously change and so it is important for the region to regularly update this strategy to account for new knowledge. For example, future studies could contain a more detailed breakdown of the transport sector and more knowledge about the biomass resource in the region. Similarly, the scenarios presented in this report are not a prediction of the future, but instead they are designed to outline the consequences of choosing different alternatives. Hence, the results are provided to inform the debate, but it will be local actors and citizens who will decide what the future energy system in the LCR will be.

- **The LCR can be a living laboratory test-case for a national conversion to a sustainable energy system.**
  The results are not only relevant to the LCR, but are indicative of the type of actions required throughout the Irish energy system to integrate more renewable energy, reduce GHG emissions and increase jobs. Therefore, by being a first mover, the LCR can demonstrate how other regions in Ireland can transition to a 100% renewable energy system also.

Summary

This study primarily analyses the economic, environmental, and resource consequences of technical energy alternatives for the LCR – and defines immediate actions that can be taken to achieve a sustainable energy system in the future.

"...renewable energy is already a cheaper alternative for electricity production than fossil fuel alternatives such as coal and gas"

Due to its characteristics, renewable energy plays a central role in this transition and so a key focus here will be to analyse the consequences of using more renewable energy in the region. It is important to emphasise from the outset that renewable energy has already transitioned from the research and development phase to an economic alternative to fossil fuels. In fact, renewable energy is already a cheaper alternative for electricity production than some fossil fuel alternatives. This is illustrated in Figure 1, which indicates that a baseload coal plant is expected to be the same price as onshore wind in 2020, while a CCGT plant will be approximately 70% more expensive than onshore wind over the lifetime of these technologies. Since the average fossil fuel prices in 2012 have already exceeded 2020 forecasts, this comparison in Figure 1 can even be considered conservative.

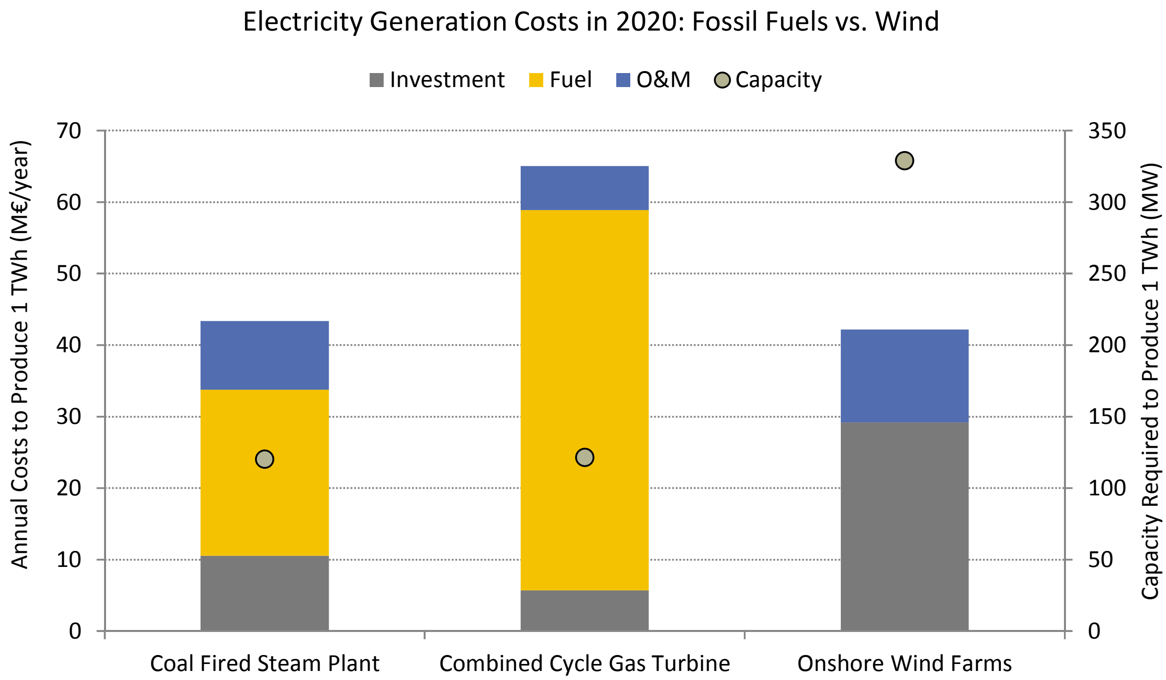

Figure 1: The cost of producing 1 TWh of electricity from a coal steam turbine, CCGT, and onshore wind based on 2020 investment costs [6], 2020 fuel price forecasts [7], and the data display in Table 3.

However, energy systems are not constructed from individual plants, but instead consist of numerous resources, conversion processes, and demands. As outlined in Figure 2, existing energy systems contain relatively simple linear relationships between supply and demand, whereas Figure 3 outlines how the interaction between components in a future low-carbon energy system becomes much more complex. Hence, renewable energy cannot be considered a cheaper alternative by comparing individual units, but instead the whole energy system and the interactions between the different components must be accounted for.

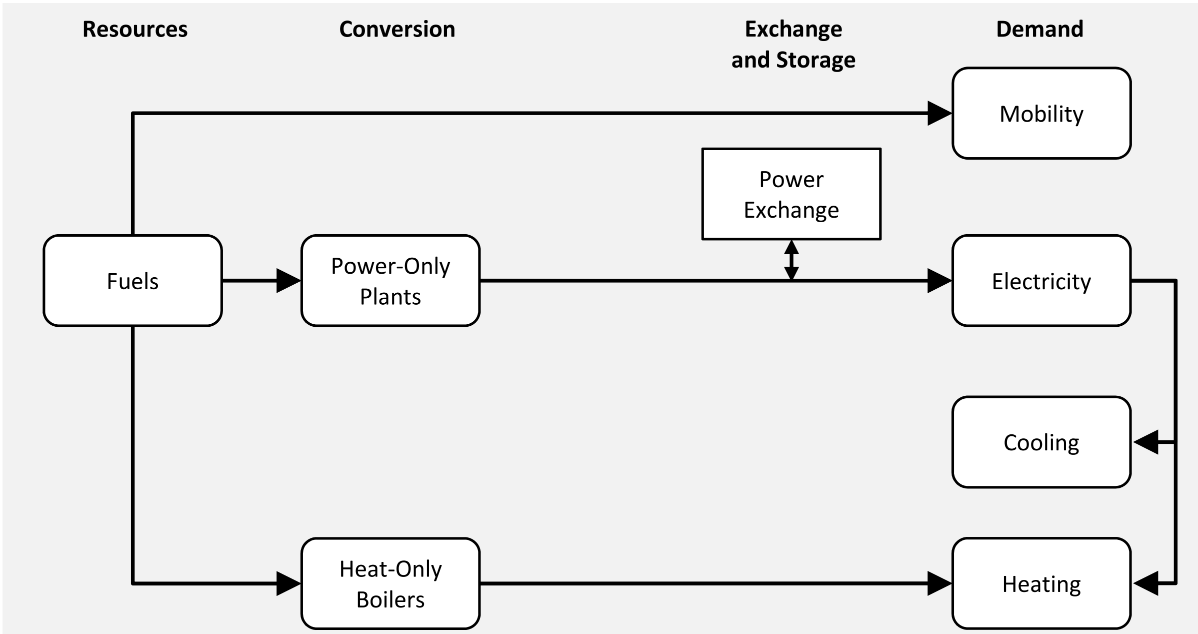

Figure 2: Interaction between sectors and technologies in the current LCR energy system [8].

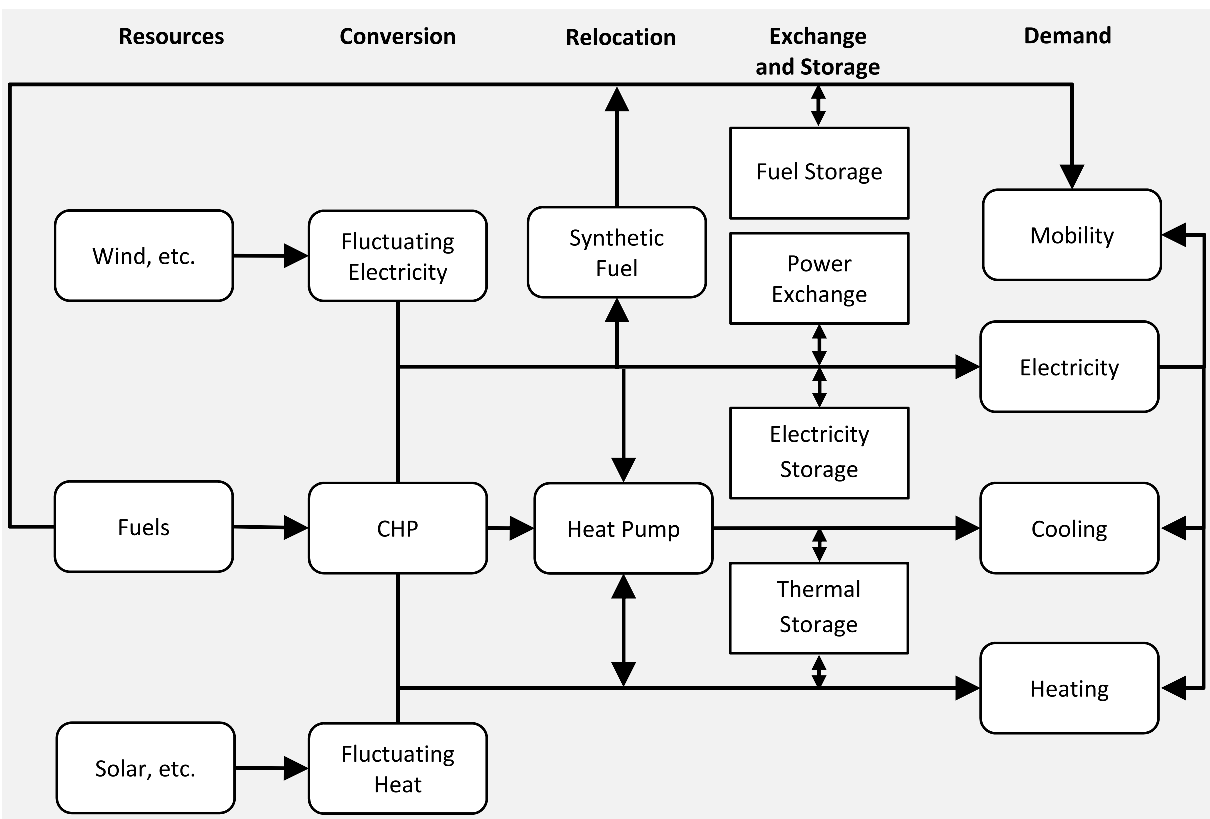

Figure 3: Interaction between sectors and technologies in a future sustainable energy system [9].

To do this, an energy systems analysis tool called EnergyPLAN has been used to simulate the LCR region in this study [10]. Figure 4 illustrates the complex interactions considered in the EnergyPLAN tool, which consists of technical inputs, costs, regulation strategies and a range of outputs.

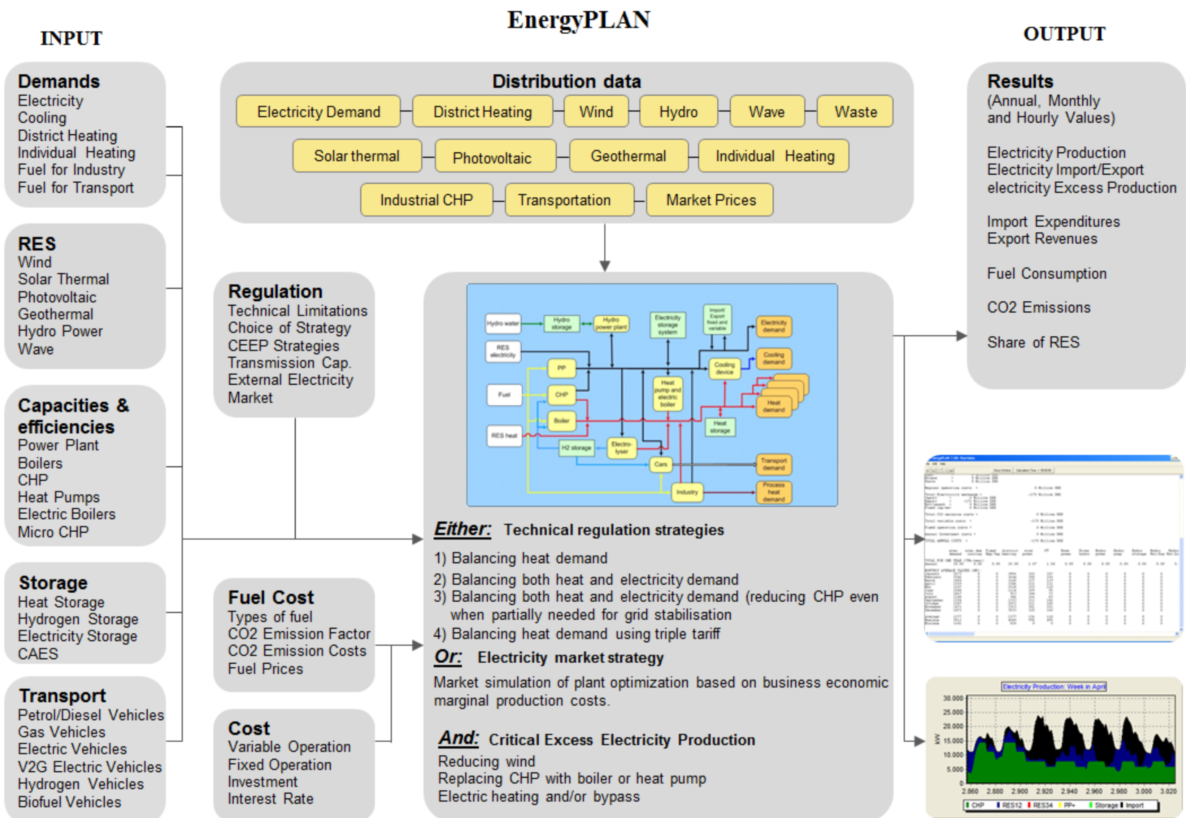

Figure 4: The structure of the EnergyPLAN tool [10].

EnergyPLAN can only be considered an aid since many of the inputs required for the tool are defined by the user. These include:

1. Time horizon
2. Technical parameters for the plants
3. Costs
4. Energy demands
5. Renewable energy resources

Two years have been considered during this study: 2020 and 2050. The year 2020 outlines the short-term actions which can be implemented in the LCR. Simulating the year 2050 ensures that these short-term actions in 2020 fit with the long-term objectives for a low-carbon sustainable energy system.

The technical parameters and costs are primarily based on published data from the Danish Energy Agency [6, 11, 12]. The energy demands for the LCR have been taken from the first part of the Limerick-Clare Energy Plan (LCEP), which is called the Energy & Emissions Balance (E&EB) [13]. Two scenarios are considered for the years 2020 based on forecasts from SEAI [14]: **Baseline** and **NEEAP/NREAP**. "The *Baseline* scenario includes all policy measures legislated for up to the end of 2009 and represents a hypothetical future scenario in which no further policy actions or measures have been taken" [14]. In other words, the *Baseline* scenario represents what will occur under existing Irish government policies without any further actions. The *NEEAP/NREAP* represents a scenario where Ireland successfully implements its EU 2020 targets: 20% energy savings and 16% of primary energy supply coming from renewables. The steps necessary for 20% energy savings are outlined in the National Energy Efficiency Action Plan (NEEAP) [15], while the actions required to achieve a 16% renewable energy share are outlined in the National Renewable Energy Action Plan (NREAP) [16]. Hence, the *NEEAP/NREAP* will illustrate the implications for the LCR if government policy is followed between now and 2020. These *Baseline 2020* and *NEEAP/NREAP 2020* scenarios were then projected forward to 2050 to estimate how the energy system will evolve over the lifetime of energy-related infrastructure. This data is essential for outlining the type and scale of energy demands that need to be met in the future so a low-carbon supply can be identified.

"...there is approximately 10 times more renewable energy in the Limerick-Clare Region (LCR) than will be required in 2020 ..."

The renewable energy resources available in the LCR have also been assessed in this study based on the methodologies proposed by Dubuisson *et al.* [17]. The results, which are presented in Figure 5, indicate that there is approximately 10 times more renewable energy in the LCR than will be required in 2020. However, a crucial constraint, which is emphasised in more detail in the main report, relates to the type of renewable resources available. As displayed in Figure 5, approximately 85% of the renewable resources available in the LCR are in the form of intermittent renewable energy sources (IRES), such as wind, wave, and tidal energy, whereas bioenergy only accounts for 15%. This simply highlights that bioenergy will be a limited resource in the future and therefore, it is very important to ensure that this resource is used efficiently and sustainably.

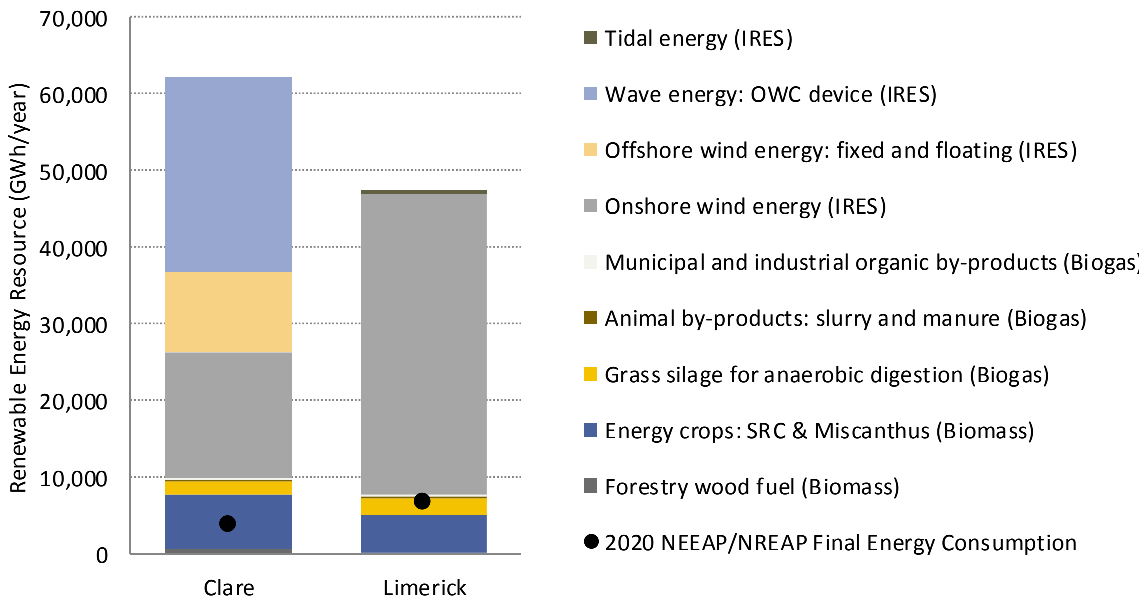

Figure 5: Renewable energy resource available in the LCR.

"If the actions outlined [here] are implemented, then 70% of electricity and 25% of the primary energy supply in the LCR will be from renewable energy by 2020"

Using the EnergyPLAN tool, the energy system in the LCR is simulated for both 2020 and 2050. The results outline how the LCR can achieve all of the following by 2020:

1. Implement more renewable energy
2. Reduce the demand for energy
3. Reduce the costs of the energy system
4. Reduce carbon dioxide emissions
5. Create approximately 2,000 more jobs

Achieving this will require that the LCR implements the specific technologies outlined under the **LCR 2020** scenario in Table 1. In summary, these actions are:

- Continue to implement the energy efficiency measures outlined in the NEEAP and presented in detail in the E&EB [13, 18].

- Continue to build more intermittent renewable energy in the region, in line with the NREAP. The primary technology is onshore wind, but other resources such as PV, wave, and tidal should also be considered, especially due to the advantages of being an early mover.
- Convert households and other buildings in urban areas from fossil fuel boilers to district heating (DH).
- Convert individual households outside of DH areas from fossil fuel boilers to individual heat pumps.
- Continue to promote individual solar thermal panels in rural households outside of DH areas.
- Use combined heat and power (CHP), surplus industrial heat, large-scale solar thermal, thermal storage, and centralised boilers to supply the heat for the district heating networks.
- Specifically focus on the development of biogas from waste resources and used for the CHP plants and centralised boilers. In addition, upgraded biogas can be used to replace natural gas in the gas grid.
- Continue to follow national targets for electric vehicles.
- Although biodiesel and bioethanol are implemented here in line with the NREAP, it is important to ensure that the resources used for these fuels are sustainable and in line with a long-term strategy for the biomass resource.

Implementing better public transport (such as bike lanes, busses, and light rail) are also very sustainable solutions, but these have not been quantified here.

Table 1: Key technical inputs for the 2020 scenarios considered in this study: a more detailed breakdown is available in Appendix IV.

Sector	Input	2020 Scenarios		
		Baseline	**NEEAP/NREAP**	**LCR 2020 (DH&HP+RE)**
Power Plants and District Heating	Condensing PP (MW)	446	479	478
	DH Demand (TWh)	0	0	0.198
	CHP (MW)	0	0	65
	Thermal Storage (GWh)	0	0	5.21
	Heat Pump (MW)	0	0	5
	Boiler (MW)	0	0	89
	Solar (TWh)	0	0	0.018
	Solar Storage (GWh)	0	0	0.390
Intermittent Renewable Electricity Sources	Wind (MW)	184	330	330
	Hydro (MW)	86	86	86
	PV (MW)	0	0	25
	Wave (MW)	0	0	0
	Tidal (MW)	0	0	10
Individual Heating	Coal Input (TWh)	0.173	0.155	0.109
	Oil Input (TWh)	1.392	0.973	0.682
	Natural Gas Input (TWh)	1.036	0.691	0.484
	Biomass Input (TWh)	0.038	0.134	0.134
	Heat Pump Heat Demand (TWh)	0.007	0.023	0.250
	Electric Heating Heat Demand (TWh)	0.289	0.268	0.201
	Solar Heat Production (TWh)	0.002	0.007	0.094
Electric Vehicles	Electricity Smart Charge (TWh)	0	0.031	0.031
	Grid to Battery Connection (MW)	0	76	76
	Battery Storage Capacity (GWh)	0	0.38	0.38
	Number of EVs	0	15,000	15,000
Biofuels	Biogas (TWh)	0	0	0.459
	Biodiesel (TWh)	0.08	0.226	0.226
	Bioethanol (TWh)	0.034	0.097	0.097

If the actions outlined under the **LCR 2020** scenario are implemented, then 70% of electricity and 25% of the primary energy supply in the LCR will be from renewable energy by 2020, as outlined in Figure 6. This will put the LCR at the forefront of renewable energy in Ireland since the national targets for renewable energy in 2020 are 16% of primary energy supply and 40% of electricity.

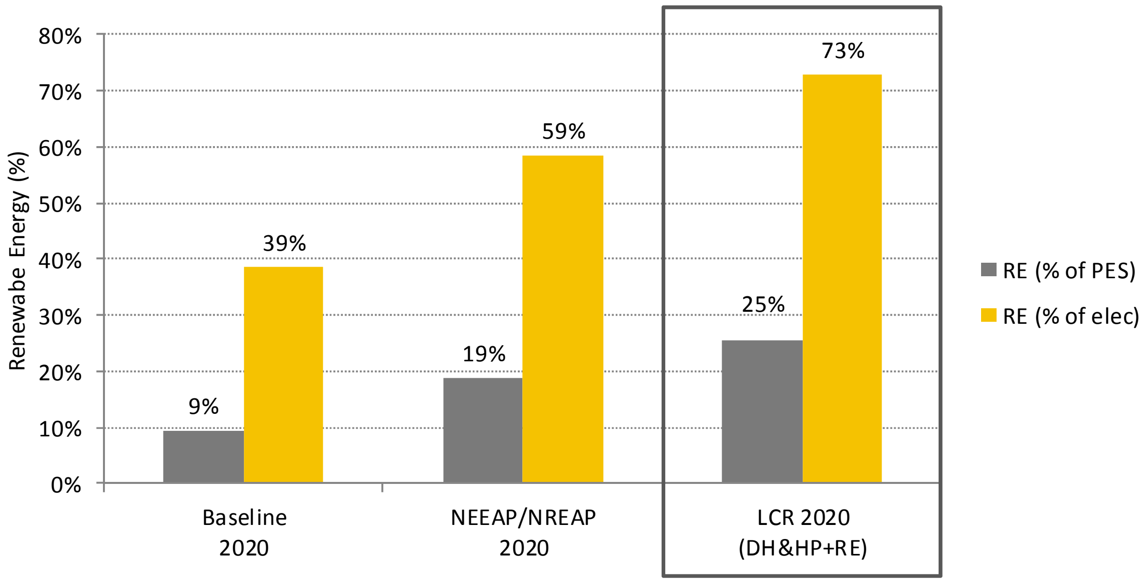

Figure 6: Renewable energy production and penetrations for the 2020 scenarios considered.

"...investment-based systems create more local jobs than fuel-based systems ... it is possible to create approximately 2,000 more local jobs in the LCR by 2020"

Even more significantly, Figure 7 indicates that the overall costs of the energy system will be lower in the *LCR 2020* scenario than in the business-as-usual *Baseline* scenario, while they are practically the same as the *NEEAP/NREAP* scenario. There is also a trend that can be noted in Figure 7: as the energy system converts from fossil fuels to renewable energy, there will also be a change in the type of costs within the energy system, from fuel-based costs to investment-based costs. For example, the *Baseline* scenario in Figure 7 consumes the most fossil fuels and hence the costs relating to fuel are highest in this scenario. In contrast, the *LCR 2020* scenario consumes the most renewable energy and hence this scenario spends the most on investments. This occurs since renewable energy technologies often have no fuel cost (such as wind, wave, PV, or tidal), but they do have high investment costs. This is important since investment-based systems create more local jobs than fuel-based systems, especially when the majority of fossil fuels are being imported [19, 20]. The number of additional jobs created in the LCR due to these increased investments in renewable energy has also been estimated in this study. If the *LCR 2020* scenario is implemented, it is possible to create approximately 2,000 more local jobs by 2020 than the business-as-usual *Baseline* scenario, while simultaneously increasing renewable energy production and reducing the overall costs of the energy system.

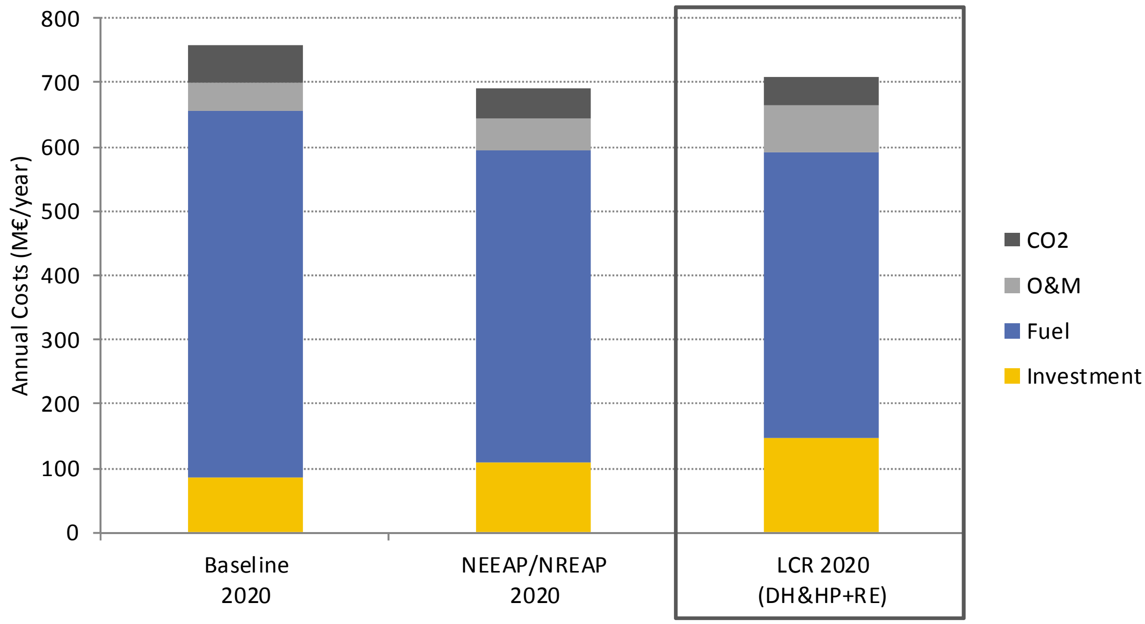

Figure 7: Socio-economic costs using 2020 investment costs, fuel prices, and CO_2 price for the 2020 scenarios considered.

"...the actions suggested here ... will contribute to the most economical 100% renewable energy system in the LCR in 2050"

However, reaching short-term targets in 2020 is only beneficial if it contributes to a long-term objective of a sustainable energy system. To ensure this, the year 2050 is also analysed in this study and the target set for that year is a 100% renewable energy system. Due to the scale of the resources available in the region and the fundamental requirement that greenhouse gas emissions must be reduced by 80-90% in Europe by 2050 [21], a 100% renewable energy system is not only possible for the region by 2050, but it may also be necessary (especially if the agricultural sector continues emitting greenhouse gases). Furthermore, this target is already being achieved by local regions around the world, such as Samsø (Denmark) [22] and Güssing (Austria) [23], while Denmark's national energy target is already to be 100% renewable by 2050 [24].

In total, nine different 100% renewable scenarios were investigated for the LCR in 2050. It is apparent from the results that the actions suggested here in the *LCR 2020* scenario will contribute to the most economical 100% renewable energy system in the LCR in 2050. Also, the results suggest that a 100% renewable energy system will be cheaper than a fossil fuel based system, although this cannot be confirmed since 2050 investment costs were not collected during this study. Other key observations from this 2050 analysis include:

- Local jobs in a 100% renewable energy system are almost triple those in a fossil fuel based system. It is estimated here that the 100% renewable energy system will create approximately 8,000 additional local jobs in 2050 compared to the fossil fuel alternative.
- The biomass resource will be constrained in a 100% renewable energy system. Hence, so alternative fuel sources to biomass for industry and alternative liquid fuels to biofuels in the transport sector are essential in the future.

"district heating is a cheaper alternative than natural gas for individual urban buildings"

From the list of actions identified, the main technology which is not utilised in Ireland to date, but plays a key role in the strategy identified in this study, is district heating. Therefore, an overview of district heating is provided in this study along with a comparison between district heating and the gas grid for heating urban buildings. The results indicate that the costs of both solutions is practically the same in 2020, but as fuel prices increase and the gas grid needs to be refurbished, natural gas will be approximately 25% more expensive than district heating in 2050. Hence, the results indicate that district heating is a cheaper alternative to natural gas for individual urban buildings.

"the transition to a sustainable energy system will not only be a technical challenge, but in equal measure, it will also be an implementation challenge"

Finally, the analysis in this study has primarily analysed the economic, environmental, and resource consequences of technical energy alternatives for the LCR in the future. However, the transition to a sustainable energy system will not only be a technical challenge, but in equal measure, it will also be an implementation challenge. To fully establish a detailed list of actions to implement the technologies outlined for 2020 will require a constant dialogue between the local authorities and other key energy stakeholders in the region. However, to inform this process, a brief discussion is presented in this study outlining the crucial role that local authorities play during the transition to a low-carbon sustainable energy system since [25]:

- Local authorities represent and can influence the interests of local communities
- Local authorities are the main coordinators between actors in the local network

- Local authorities already have the responsibility for other fields of strategic planning
- Local authorities constitute the link between central policy making and local communities, and as such translate national goals into local action.

In short, local authorities possess or can access the necessary types of expertise required to co-ordinate the transition to renewable energy in the LCR. Through their roles as planning authorities, initiators, facilitators, investors, and owners of renewable energy solutions, local authorities can be the main drivers in 100% renewable energy planning.

Limerick Clare Energy Agency

This report has been prepared for the Limerick-Clare Energy Agency (LCEA) [26]. The LCEA was established in 2005 with equal investment from Limerick County Council and Clare County Council. The agency is also fortunate to enjoy the support of the LEADER groups in Clare, West-Limerick and Ballyhoura; in addition to The University of Limerick and Aerobord Ltd.

LIMERICK CLARE energy agency

The LCEA aims to provide energy solutions for sustainable development in the region. The agency provides energy services to all economic sectors and the general public, promoting and facilitating efficiency and sustainability in the production and consumption of energy. The top ten areas of interest for the agency are:

1. Promote Public Awareness of Energy & Climate Change Issues.
2. Evaluate Energy Consumption in Clare & Limerick.
3. Evaluate Energy Related Emissions for Clare & Limerick.
4. Develop an Energy & Emissions Balance for Clare & Limerick.
5. Support & Develop Renewable Energy Production, Distribution & Training Programmes.
6. Conduct Energy Audits & Benchmarking of Public Buildings and Facilities in Clare & Limerick.
7. Promote Cooperation and Links to Community Groups (LEADER etc.)
8. Promote Research & Development Partnerships with Third Level Education Bodies.
9. Promote Energy Efficiency and Environmental Awareness to all Commercial Energy Consumers.
10. Promote the Establishment of Low Carbon Commerce.

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Nomenclature

Abbreviation	Description
CCGT	Combined Cycle Gas Turbine
CHP	Combined Heat and Power
DH	District Heating
DME	Dimethyl Either
E&EB	Energy and Emissions Balance
EV	Electric Vehicle
HP	Heat Pump
IEA	International Energy Agency
IRES	Intermittent Renewable Energy Sources
GHG	Greenhouse Gas Emissions
HDD	Heating Degree Days
LCEP	Limerick Clare Energy Plan
LCR	Limerick-Clare Region
LEU	Large Energy User
NEEAP	National Energy Efficiency Action Plan
NREAP	National Renewable Energy Action Plan
O&M	Operation and Maintenance
PES	Primary Energy Supply
PHES	Pumped Hydroelectric Energy Storage
PP	Power Plant
RE	Renewable Energy
RES	Renewable Energy System
SEAI	Sustainable Energy Authority of Ireland
TIS	Transmission Interface Stations

1 Introduction

The energy system will need to undergo radical technological change over the next few decades if issues such as climate change, pollution, depleting fossil fuel reserves, and increasing energy costs are to be overcome. Sperling *et al.* has characterised this transition in Figure 8 [25], which illustrates the type of challenges that need to be overcome including increased intermittent renewable energy, energy efficiency improvements, and the re-organisation of the institutions within the energy sector.

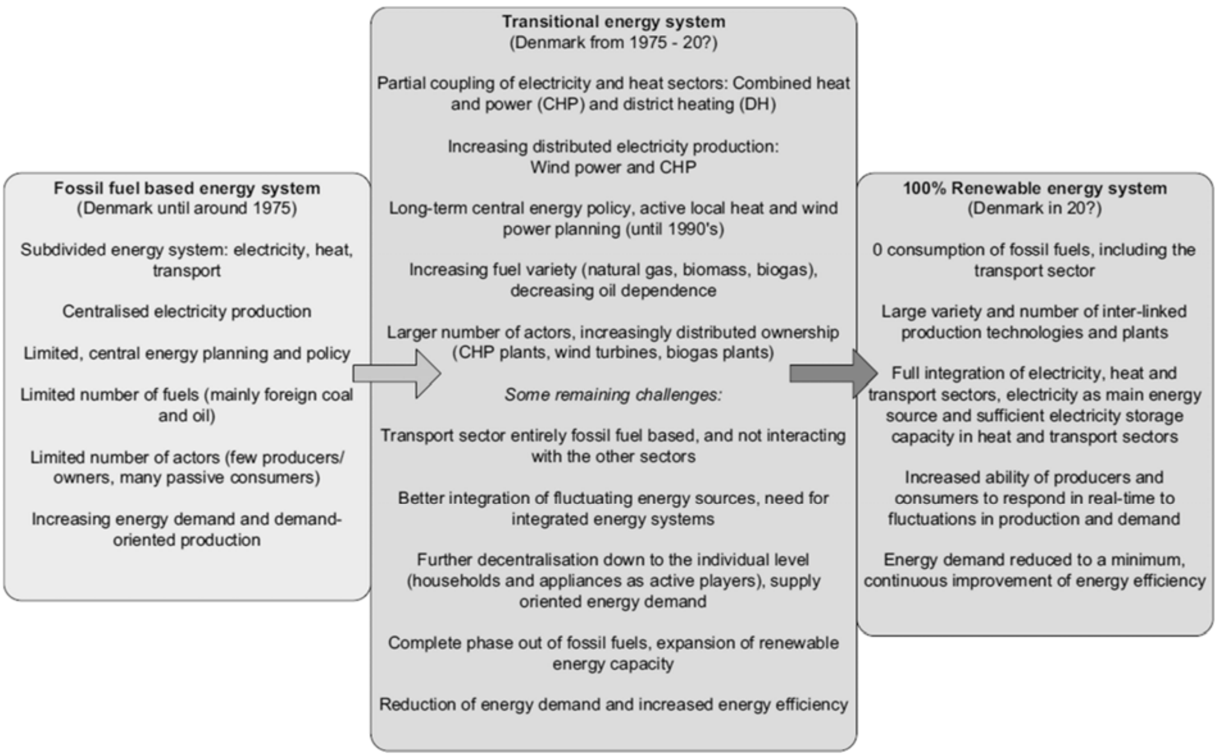

Figure 8: Phases of transition from the current to a sustainable energy system [25].

Although this is a long-term process, actions need to begin today. In fact, this transition has already begun around the world with some local authorities already branding themselves as 100% renewable energy regions [22, 23]. However, this transition is not occurring by itself since historically, the energy system is designed for fossil-fuel based technologies. As outlined in Table 2, these technologies have very different characteristics to renewable energy technologies. Therefore, the transition to a sustainable energy system will require radical technological and organisational change, which will require support from national and local governance.

Table 2: Typical characteristics of fossil fuel and renewable energy based technologies.

Fossil Fuels	Renewable Energy	
Low Investment Costs	High Investment Costs	Why markets suit fossil fuels
High Operational Costs	Low Operational Costs	
Predictable Generation	Intermittent Generation	
Mature Technology	Partly Immature Technology	
Imported Fuel	Indigenous Resource	Why renewable energy benefits local citizens
Centralised Production	Decentralised Production	
Polluting	Clean	
Unsustainable	Sustainable	

It is also important to recognise that renewable energy no longer means more expensive energy. This estimated here based on the predicted 2020 technical performance (Table 3), investment costs [6], and fuel prices [7] for a coal power plant, a combined cycle gas turbine (CCGT), and onshore wind farms. Based on the assumptions here, Figure 9 indicates that wind power can produce 1 TWh of electricity at the cheapest price. In fact, a CCGT (combined cycle gas turbine) plant is approximately 70% more expensive than wind. Since the average fossil fuel prices in 2012 have already exceeded 2020 forecasts, this comparison in Figure 9 could be considered conservative.

Table 3: Data used to estimate the annual cost of producing 1 TWh of electricity from a coal steam turbine, CCGT, and onshore wind [6]. An interest rate of 3% was used to annual the costs.

Plant	400-700 MW Coal Steam PP		100-400 MW CCGT		Wind Farm (Onshore)	
Year	2020	2050	2020	2050	2020	2050
Technical Availability	95%	95%	94%	94%	97%	98%
Electrical Efficiency	46%	53.5%	57%	62%	n/a	n/a
Capacity Factor	n/a	n/a	n/a	n/a	33.7%	37.1%
Lifetime (years)	40	40	25	25	20	30
Cost of Fuel (€/GJ)	3.1	3.4	9.1	12.2	n/a	n/a

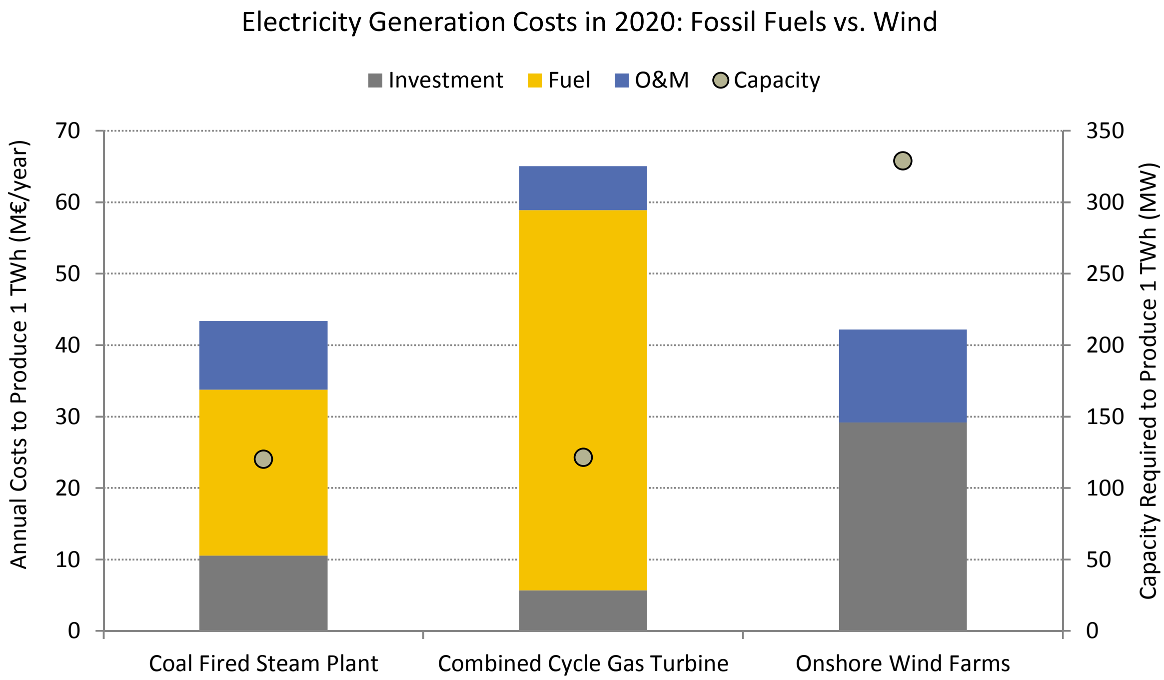

Figure 9: The cost of producing 1 TWh of electricity from a coal steam turbine, CCGT, and onshore wind based on 2020 investment costs [6], 2020 fuel price forecasts [7], and the data displayed in Table 3.

Looking to 2050, which is within the lifetime of some of these technologies, the cost of wind power is going to be reduced, while the cost of fossil-fuel based plants is going to increase: this is due to forecasted increases in fuel prices, while investment costs are expected to reduce. As a result, Figure 10 indicates that by 2050, the coal plant will be over 30% more expensive than wind while the CCGT plant will be approximately double. Naturally energy systems are much more complicated than a single production plant since demand changes, technologies change, and in the case of some renewable energy, even the production is unpredictable. As a result, this study will investigate if the LCR energy system can operate with renewable energy in a reliable fashion, while still maintaining its economic advantage over the fossil fuel alternatives.

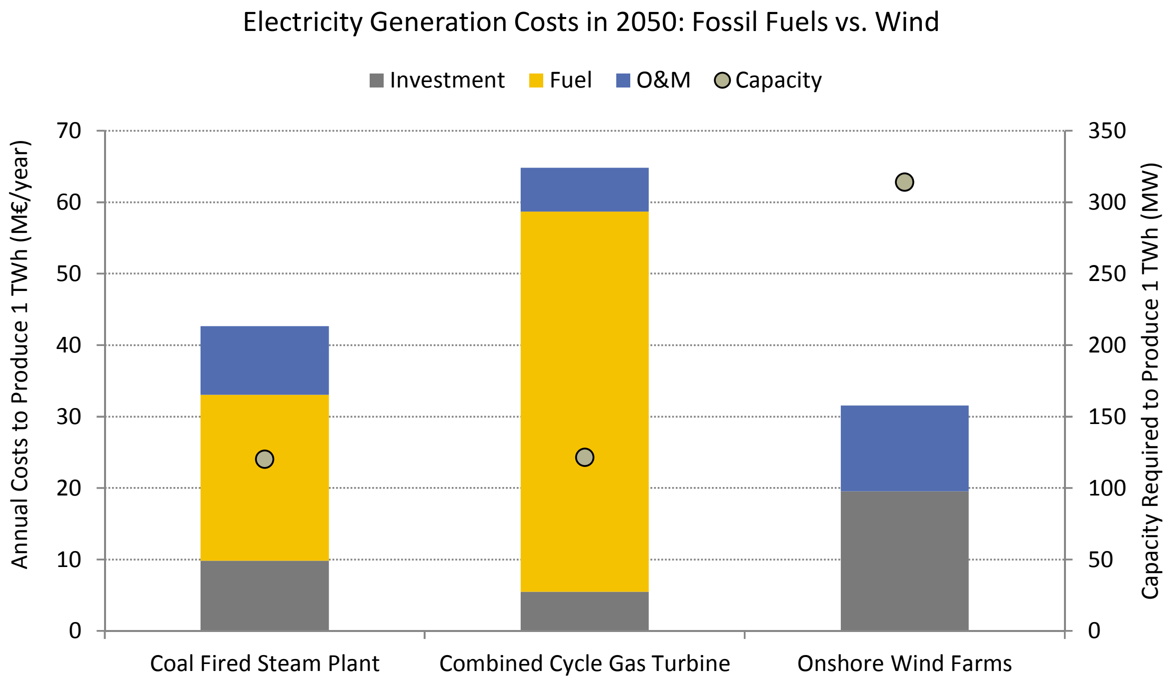

Figure 10: The cost of producing 1 TWh of electricity from a coal steam turbine, CCGT, and onshore wind based on 2050 investment costs [6], a projection of fuel price forecasts to 2050 [7], and the data display in Table 3.

Before completing this analysis, it is also important to recognise that a sustainable energy system will not just depend on economics: there are also numerous societal benefits which are not easily quantified in a technical or economic analysis. For example, this is a non-exhaustive list of the regional benefits when converting to a sustainable energy system:

- Citizens: security of energy supply, more jobs, and reduced energy costs.
- Education: innovation within teaching and local businesses.
- Environment: greenhouse gas emissions can be eliminated.
- Business: reduced energy costs, new technologies, new jobs, new skills, new companies, security of energy supply with more stable prices.
- Industry: stable long-term energy prices which will attract new industries and businesses.
- National: A living laboratory test-case for a national conversion to a sustainable energy system.
- Brand: a new brand to advertise the region and also to attract industry and tourism (already been utilised today [22, 23, 27]).

Many of these benefits will need to be assessed qualitatively based on the strategic interests of the region, desires of local citizens, and the objectives at a national level. To date, the Irish government has recognised these benefits in renewable energy by outlining ambitious plans for the future. The most recent report at national level was released in May 2012 outlining the following as some of the key energy challenges to overcome in Ireland [4]:

- Need predictable and transparent support frameworks to attract investment
- Need for regulatory certainty which supports renewable energy development
- The impact of large scale penetration of renewable technologies on the overall energy system with regard to overall cost efficiency and system reliability
- Balancing the supply and demand challenges inherent in the bioenergy sector and ensuring the resource is used in a sustainable manner
- Tackling the barriers for renewable heat demand including CHP and district heating systems

In addition, the report outlined the role of local authorities by emphasising the need for Local Authority Renewable Energy Strategies [4]. Hence, the focus here in this study is extremely relevant for the local authorities in the LCR at present.

This report builds on the first part of the Limerick Clare Energy Plan (LCEP), which is called the Energy & Emissions Balance (E&EB) [13]. In the E&EB, strategic energy planning has been described in detail and the final energy consumption in the LCR has been quantified. This report, which is called the Climate Change Strategy, analyses the energy system in the Limerick Clare Region (LCR), from a resource, demand and production perspective to identify what actions can be taken in the short (2020) and long-term (2050) towards a low-carbon energy system for the region. It begins by outlining the methodology used to analyse the energy system in the LCR (section 2). This outlines the key principals used to assess the energy system in this study and also describes how these key principals have been considered. Section 3 follows with a summary of the energy demands and renewable energy resources within the LCR: this demonstrates the type and scale of energy demands which need to be met in the region as well as the renewable energy available to meet these demands. Afterwards, the methodology from section 2 is used to assess different energy scenarios for the LCR in terms of their demands, costs, job creation, and environmental implications (section 4). Four different scenarios are considered for 2020, which demonstrate how renewable energy can be increased, more local jobs can be created, and greenhouse gas emissions reduced. These results are supplemented by a 2050 analyses which ensures that the actions recommended in 2020 fit with the long-term objective in the LCR of a more sustainable energy system.

Since district heating is not a well-established technology in Ireland, but it is recommended for the LCR in this report, section 5 discusses the benefits of district heating in more detail. It also includes a comparison between district heating and natural gas for heating individual urban dwellings. The results are also discussed briefly in the context of the national energy system in section 6 to outline how the LCR can be part of a sustainable energy system for Ireland. In section 7 the role of the local authorities during the implementation of a sustainable energy system is highlighted to demonstrate how they can play a central role in this process. Finally, the report concludes with some key recommendations in relation to the energy system in the LCR (section 8).

2 Methodology

Any methodology used to develop future energy scenarios is open to deliberation, since the future is always uncertain. However, this uncertainty can be at least debated by ensuring that a methodology is clearly presented. Hence this section presents the key principles used to define the methodology in this study followed by a brief overview of how these key principles were considered. It is supplemented by a range of data in the Appendices.

2.1 Key Principles

The key principles that define how the analysis is completed are:

1. The analysis must consider all sectors of the energy system: electricity, heat, and transport.
2. Consider radical technological change
3. A long-term time horizon must be considered
4. Renewable energy fluctuations need to be accounted for
5. The analysis must be completed from a socio-economic perspective
6. The actions identified in this study can be independently implemented by the LCR

Firstly, the analysis will need to consider the whole energy system (i.e. not just one specific sector) along with radical technological change. Not only does this mean that electricity, heat, and transport need to considered from both a consumption and production perspective, but it should also be possible to assess radical technological changes in each of this sectors. The significance of this is evident when considering the transition necessary from the existing energy system (Figure 11) to a future renewable-energy based system (Figure 12). Unlike the existing energy system which consists of only a few linear relations between the resources and demand (Figure 11), a future energy system will include numerous interactions between the resources, conversion processes, and demands (Figure 12). Therefore, when evaluating a future energy system, it is important to consider the impact that a technology can have across the entire energy system along with the consequences of a radical technological change in any one of these sectors.

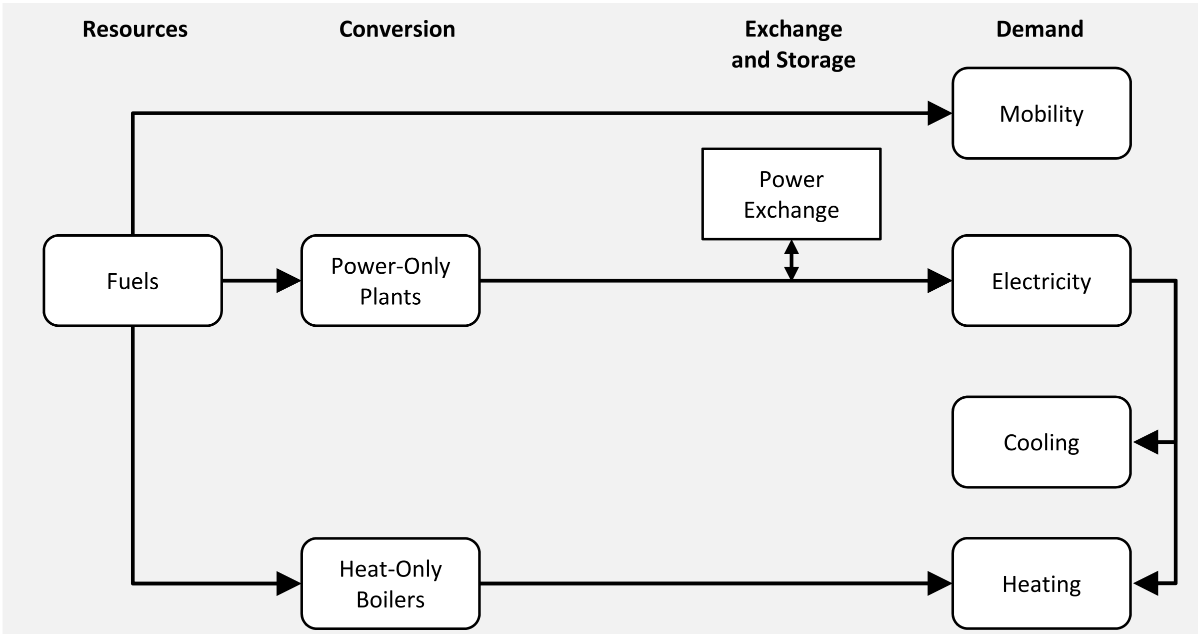

Figure 11: Interaction between sectors and technologies in the current LCR energy system [8].

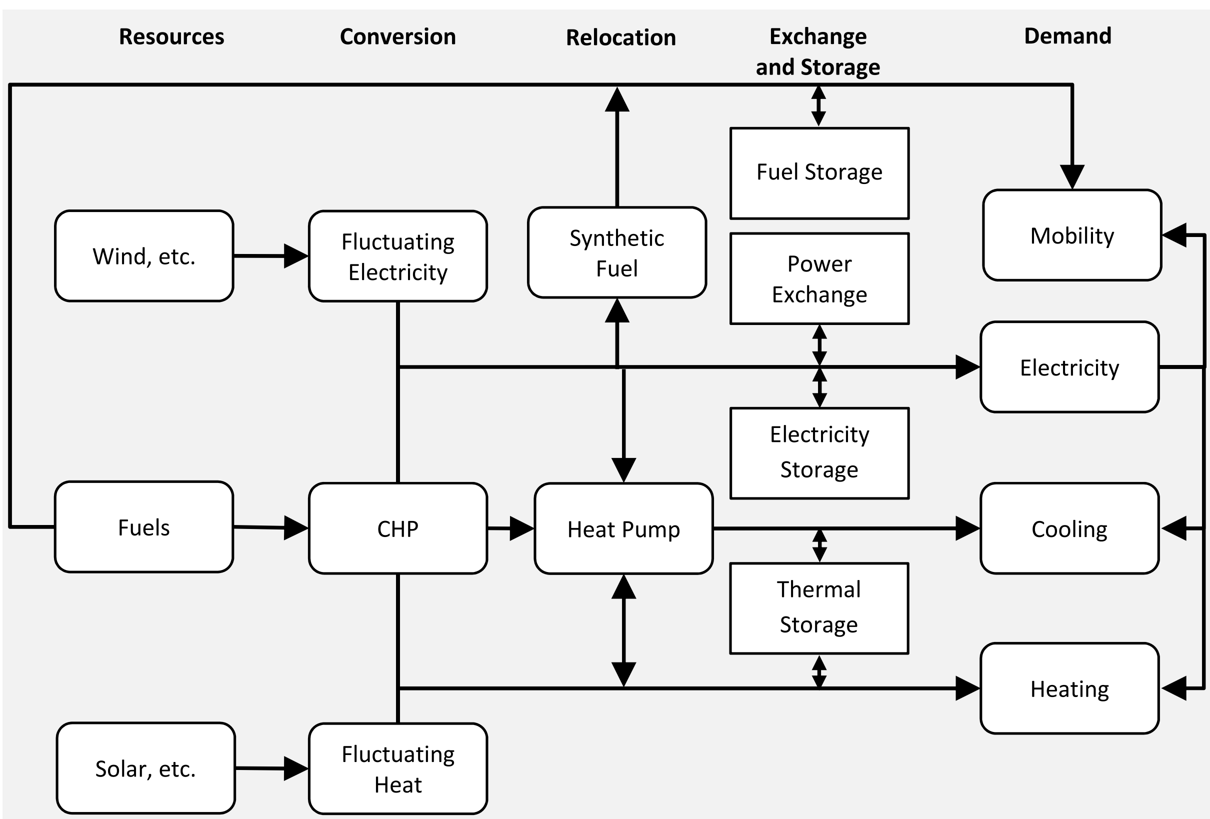

Figure 12: Interaction between sectors and technologies in a future sustainable energy system [9].

Secondly, the timelines considered in this study will need to consider the short-term fluctuations of intermittent renewable energy sources (IRES) across a long-term time horizon. It is important to consider the short-term fluctuations of IRES to account for intermittency and to ensure that the demand for electricity, heat, and transport is always met. The long-term time horizon is important from a technical perspective due to the lifetime of the technologies being considered. As outlined in Figure 13, according to the International Energy Agency (IEA) energy production units have a lifetime of more than 20 years, energy networks have a lifetime of approximately 40 years, and some energy-related infrastructure can have a lifetime of 100 years or more. Consequently, the actions taken today will need to aid the operation of the future energy system displayed in Figure 12 and not the existing energy system displayed in Figure 11 This means that it is essential to plan for a long-term vision when evaluating energy systems for the future. Without this long-term perspective, a lot of money and resources could be spent today on actions that do not fit with the future sustainable energy system (Figure 12). More detailed examples relating to the biomass resource (section 4) and the gas network (section 5) will demonstrate this later in the report.

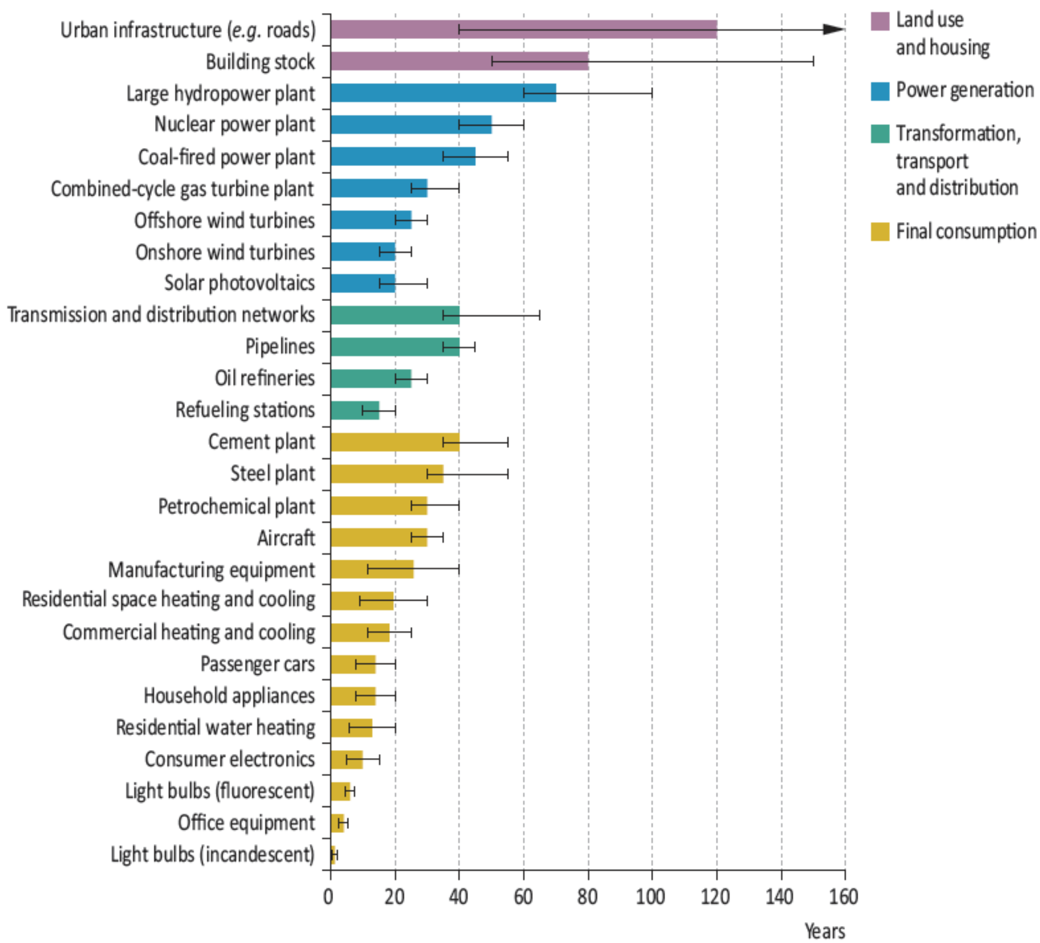

Figure 13: Typical lifetime of energy-related capital stock according to the IEA [28]: The solid bars show average lifetimes while the range lines show typical variations.

Thirdly, the future energy systems need to be evaluated from a socio-economic perspective [3], since markets often do not reflect benefits such as less pollution, lower GHG emissions, resource depletion, land-use change, waste, and security of supply. As outlined in the introduction, a renewable energy system will be based on investments and not fuels. Naturally this transition will require many organisations to change. However, designing the energy system for the profits of one individual organisation is not the key concern for the citizens in a local society. Instead, it is the overall cost of energy, the type of resources used (i.e. environment), the number of jobs created, and the balance of payment for the region that are examples of the key metrics which define a good or bad energy system from a society's perspective. Thus, future energy systems should be considered without imposing the limitations of existing institutions or regulations. For example, the existing electricity market is not designed for the future energy system in Figure 12 and so the future energy system should not be designed within its framework. Therefore, when assessing the future energy system, it needs to be optimised from a societal perspective, and not from an individual organisation perspective.

Fourthly, the analysis here will focus on what the LCR can do for the LCR, and not what the LCR can do for the rest of Ireland or elsewhere. In other words, when the energy system is being analysed, it is assumed that the LCR behaves like an isolated 'island'. This assumption does not mean that the LCR will not import/export energy from/to other regions in Ireland. In fact, if Ireland is to develop a low-carbon energy system, a wind-rich rural area like the LCR will have to export wind energy to the more populated areas in the East of Ireland. However, in this study, this assumption is applied to the methodology for these two critical reasons:

1. To ensure that the actions identified for the LCR in this study will not affect the actions taken elsewhere in Ireland. In other words, the IRES capacities recommended here comply with the national grid regulations defined by EirGrid [29] so the LCR should be permitted to install at least these capacities.
2. In a future where the whole of Ireland has a low-carbon energy system, balancing IRES will become a key challenge. Therefore, by assuming that the LCR is an isolated island in this study, we are ensuring that the LCR develops the balancing technologies required to integrate IRES and doesn't simply export/import the problem. In this way, the LCR is accommodating a national low-carbon energy system.

In summary, the methodology used in this study will try to include all sectors of the energy system, consider radical technological change, account for the hourly fluctuations of IRES, use a long-term time-horizon, evaluate the results from a socio-economic perspective, exclude the limitations associated with existing institutional designs, and identify independent actions for the LCR. Considering these issues includes a number of complex technical and economic relationships and so the EnergyPLAN tool will be used to aid the analysis in this study.

2.2 How EnergyPLAN is Used to Account for the Key Principles

EnergyPLAN is an energy system analysis tool specifically designed to assist the design of national or regional energy planning strategies under the "Choice Awareness" theory [10, 30]. It has been developed and expanded on a continuous basis since 1999 at Aalborg University, Denmark [31]. As a result, it is now a very complex tool which considers a wide variety of technologies, costs, and regulations strategies for an energy system. The algorithms used to create the tool are described in detail in the user manual [32] and hence these are not discussed here. Instead, the key features available in the tool and how they are used to account for the key principals of the methodology are presented.

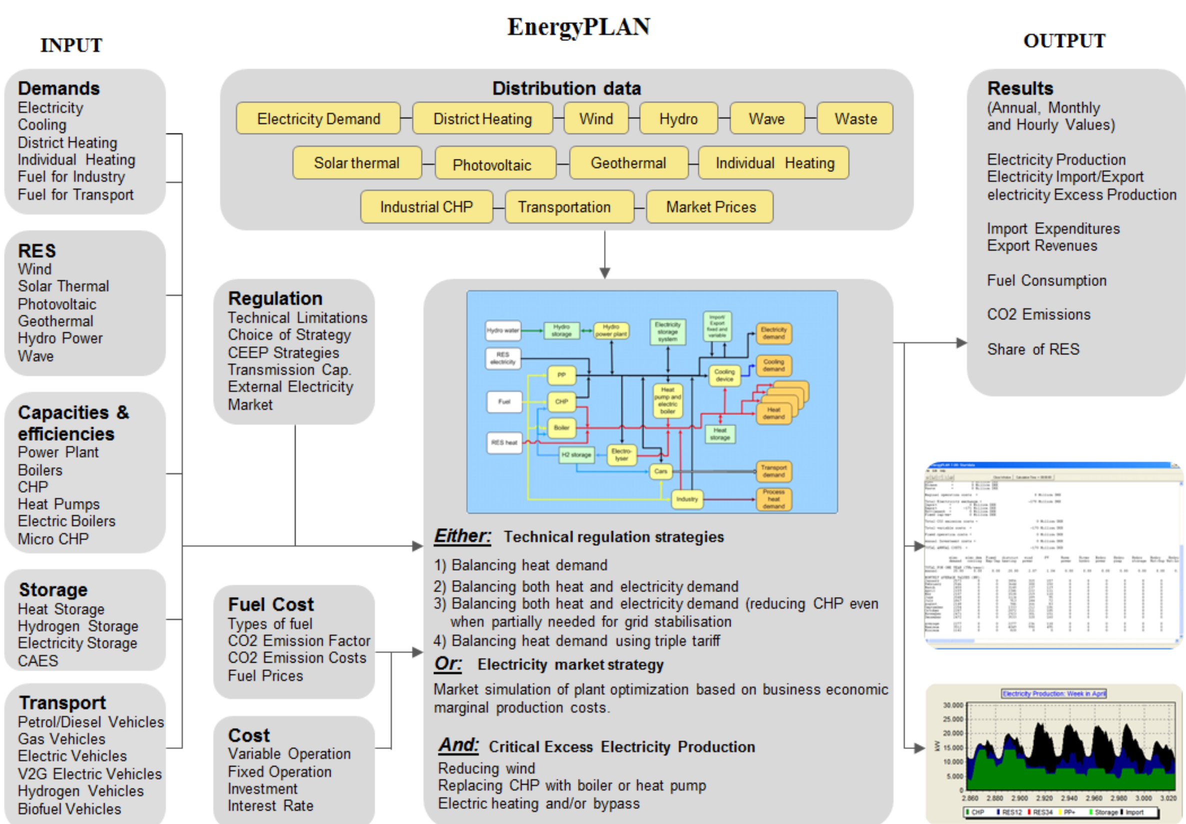

Figure 14: The structure of the EnergyPLAN tool [10].

2.2.1 Considering the Whole Energy System

In line with selected methodology, EnergyPLAN considers all sectors in the energy system: electricity, heat, and transport, as outlined in Figure 15. Also, since the tool has been developed on a research basis, it includes a number of new technologies which incorporate radical technological change. This is demonstrated by the many analyses that EnergyPLAN has been used for to date. These include an analysis of the large-scale integration of wind [33] as well as optimal combinations of renewable energy sources [34], management of surplus electricity [35], the integration of wind power using Vehicle-to-Grid electric-vehicles [36], the implementation of small-scale CHP [37], integrated systems and local energy markets [38], renewable energy strategies for sustainable development [39], the use of waste for energy purposes [40], the potential of fuel cells and electrolysers in future energy-systems [41, 42], the potential of thermoelectric generation in thermal energy systems [43], various renewable fuels for transport [44], and the effect of energy storage [8], with specific work on compressed-air energy storage [45, 46], pumped-hydroelectric energy storage [47, 48], and thermal energy storage [31, 33, 49]. In addition, EnergyPLAN was used to analyse the potential of CHP and renewable energy in Estonia, Germany, Poland, Spain, and the UK [50]. EnergyPLAN has been used to simulate a 100% renewable energy system for the island of Mljet in Croatia [51], the local authorities of Frederikshavn [52, 53] and Aalborg [54], as well as the countries of Ireland [55] and Denmark [44, 56, 57]. Other publications can be seen on the EnergyPLAN website [10], another overview of the work completed using EnergyPLAN is available in [30], and a comparison with other energy tools is available in [58]. Based on this research, EnergyPLAN is clearly capable of analysing all sectors in the energy system along with new technologies.

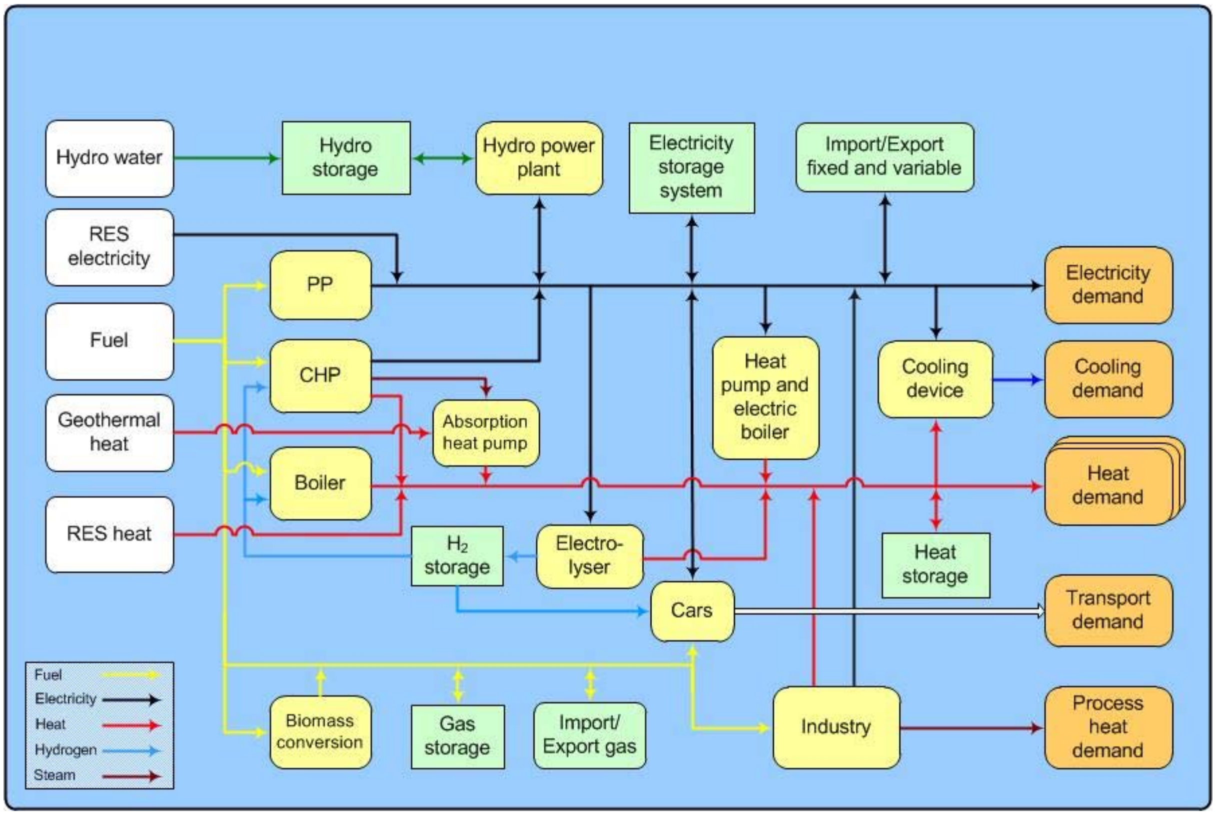

Figure 15: Flow chart of resources, conversion technologies, and demands considered in EnergyPLAN [10].

2.2.2 Accounting for Intermittency and a Long-Term Time Horizon

Secondly, EnergyPLAN simulates the energy system on an hourly basis over one year. The hourly time-step is essential to ensure that intermittent renewable energy is capable of reliably meeting the demands for electricity, heat, and transport. A detailed description of the hourly demand profiles created for the EnergyPLAN tool is available in Appendix I.

To ensure a long-term time horizon is considered, two years will be simulated: 2020 and 2050. In 2020, the objective will be to develop short-term actions which can be taken by the LCR to increase renewable energy production, reduce energy costs, reduce GHG emissions, increase employment, and improve the net balance of payment. A 2050 scenario will also be established to ensure that the short-term actions in 2020 are in line with the long-term objectives of a low-carbon energy system for the region.

2.2.3 Using a Socio-Economic Perspective

In relation to the socio-economic perspective, EnergyPLAN optimises the technical operation of a given system as opposed to tools which identify an optimum within the regulations of an individual sector. As a result, the tool focuses on how the overall system operates instead of maximising investments within a specified market framework. The results will quantify the primary energy supply (PES), renewable energy penetration, GHG emissions, and energy system costs. All costs are annualised according to Equation 1, which consists of the total investment costs *I*, the installed capacities *C*, lifetimes *n*, an interest rate *i*, and the annual fixed O&M costs as a percentage of the total investment.

$$I_{Annual} = (IC)\left\{\left[\frac{i}{1-(1+i)^{-n}}\right] + O\&M_{Fixed}\right\} \quad (1)$$

In this way, various scenarios consisting of different technology mixes can be compared with one another. The fuel costs, investment costs, and operation and maintenance (O&M) costs used in this study are presented in Appendix II. EnergyPLAN does not calculate the job creation and balance of payment for the region, so this was completed outside the tool: the methodology used is demonstrated in the results section where actual figures from the analysis are utilised (section 4).

2.2.4 Independent Actions for the LCR

While completing the energy system analysis in this study, it will be assumed that there is zero export transmission capacity available for the LCR. However, it should be noted that a brief sensitivity analysis is carried out for 2020 to illustrate the additional IRES that can be constructed in the LCR if the existing export capacity is utilised (section 6).

3 Energy Demand and Renewable Energy Resources

Before completing an energy systems analysis, it is important to understand the demands that need to be met and the renewable energy resource locally available to meet them. The demands are important since they indicate the type and scale of energy required. For example, oil used for transport is much more difficult to replace with renewable energy than oil used for individual boilers. Similarly, it is important to be aware of the renewable energy resources available so that suitable technologies can be identified for the future. For example, if there is an abundant wind energy resource in a region, then some form of electricity-based technologies should be promoted ahead of combustion-based technologies. Therefore, this sections shows the demands and renewable energy resources identified within the LCR before analysing the different energy scenarios in section 4.

3.1 Energy Demands in 2020 and 2050

The first part of the LCEP which supports this report is called the "Energy and Emissions Balance (E&EB)". This document gives a detailed overview of how the energy demand for the LCR is constructed for the years 1990-2010 as well as the two 2020 scenarios: *Baseline* and *NEEAP/NREAP*. Since the methodology in this study also requires a long-term scenario, the *Baseline 2020* and *NEEAP/NREAP 2020* scenarios were project forward to 2050. To do this, it is assumed that the growth rates between 2010 and 2020 continue out to 2050. The resulting final energy consumption is presented in Figure 16 and the primary energy supply is in Figure 17. A detailed breakdown is provided in Appendix III.

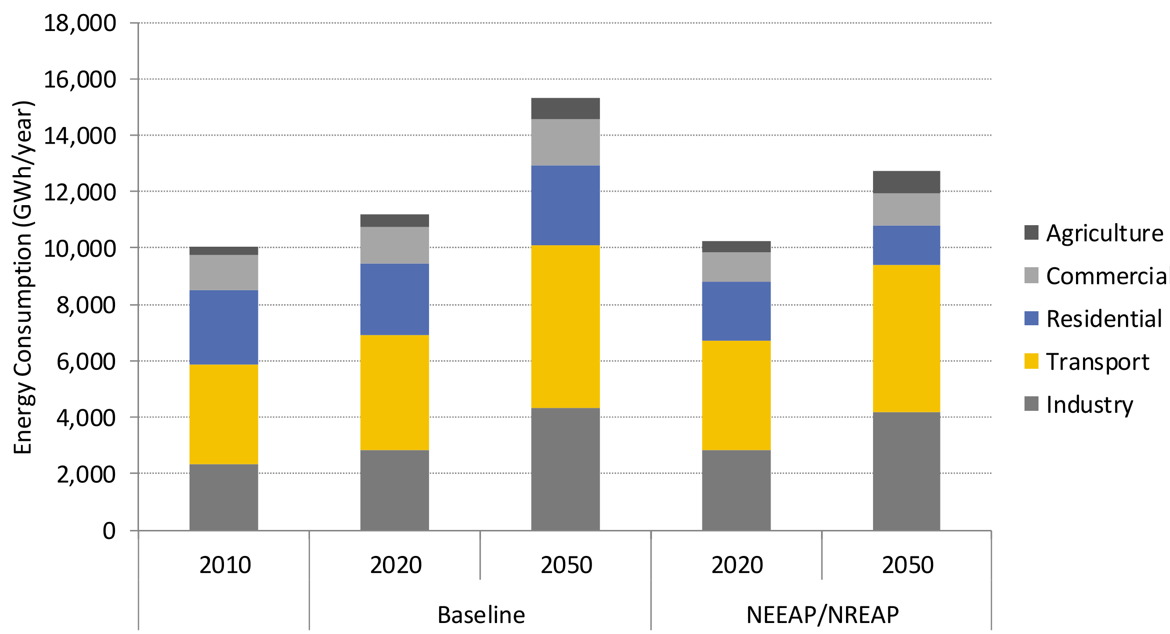

Figure 16: Final energy consumption in the LCR in 2010, 2020, and 2050 [13].

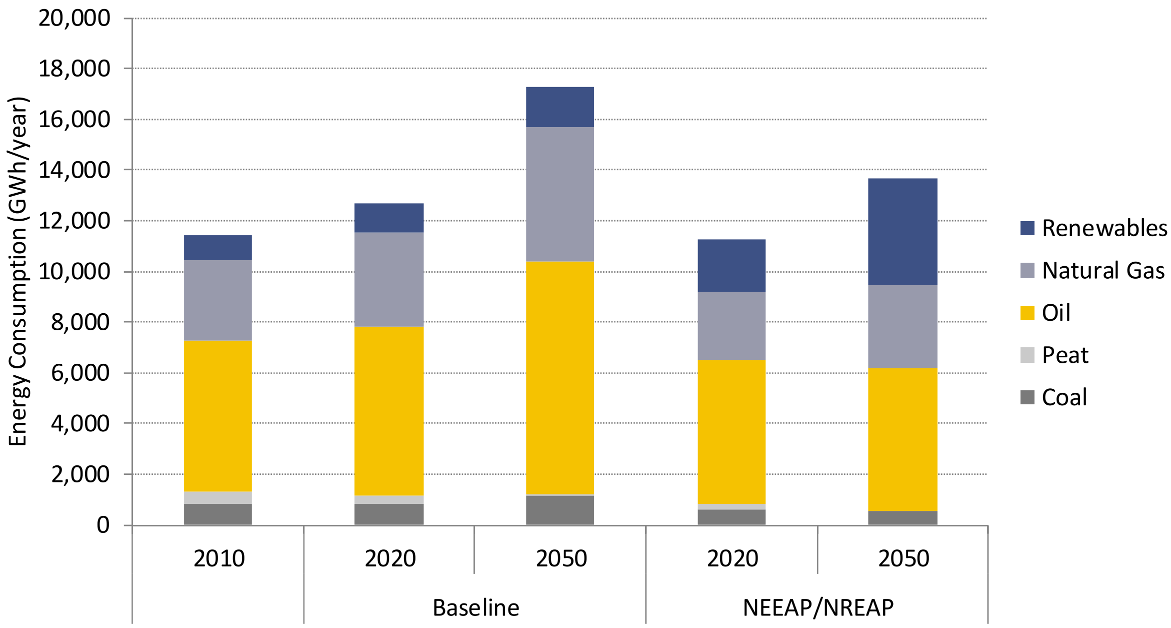

Figure 17: Primary energy supply in the LCR in 2010, 2020, and 2050 [13].

3.2 Local Renewable Energy Resources in the LCR

As well as the energy demands that must be met, it is also important to understand the type and scale of renewable energy resources available in the LCR before completing the energy system analysis. Unlike fossil fuels which from an LCR point of view are all effectively imported stored energy in solid (coal), liquid (oil), or gas (natural gas) state, renewables come from a variety of resources in a variety of forms. A separate report was therefore carried out specifically to investigate the type and quantity of renewable resources indigenously available within the region. The full report is available in Appendix VIII while a summary of the results is provided in Figure 18. Here it is evident that the LCR has a substantial renewable energy source, which could potentially be up to 10 times more than the 2020 final energy consumption in the region. This leads to the first key conclusion: the LCR has enough renewable energy in the region to meet all of its energy needs. Therefore, if the region wants to have a low-carbon energy system in the future, it will be possible to do so. Naturally, having an adequate resource is not the only concern since many others such as costs, mix of technologies, and security of supply are also important. Hence, the energy system analysis in this study will quantifies some of these metrics also.

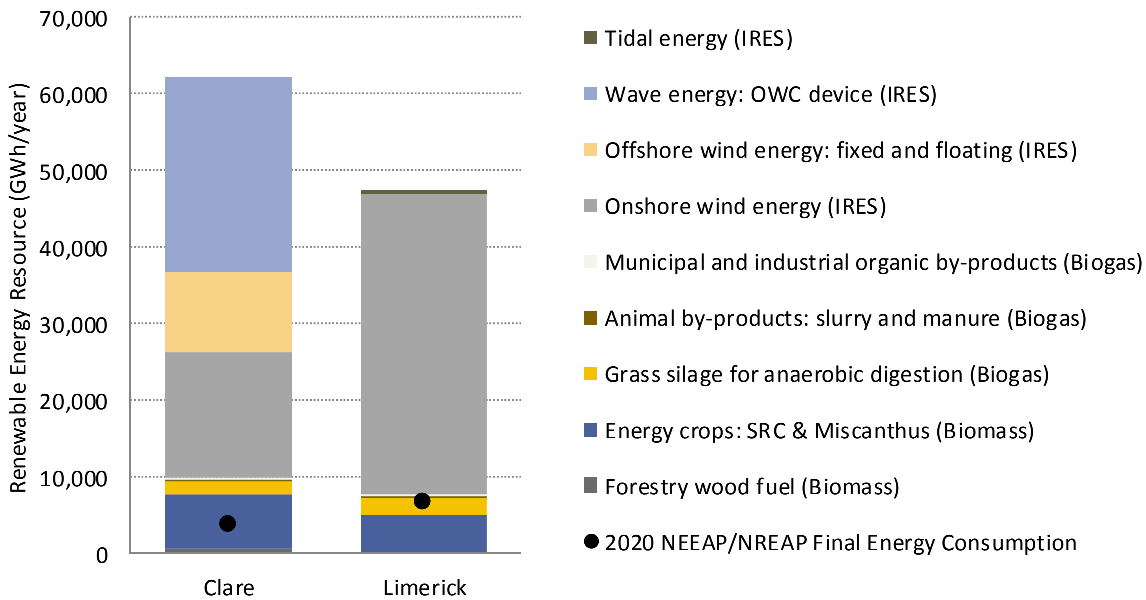

Figure 18: Renewable energy resource available in the LCR (Appendix VIII).

4 Energy Scenarios for 2020 and 2050

Considering the range of potential technologies, the long-term time horizon, and the various regulation strategies available, the number of potential scenarios that could be investigated in this study is far more than viable within one study. Hence, the focus in this study has been refined based previous research completed, the energy demands identified for the LCR [13], and the renewable resources available within the LCR (see section 3.2 and Appendix VIII). It was decided that the long-term objective for the LCR is a 100% renewable energy system, particularly considering the following:

1. The renewable energy resource within the region is far greater than the forecasted demand.
2. There are currently no fossil fuel resources available in the region.
3. The long-term objective for Ireland and the EU is to reduce CO_2 emissions by 80-90% by 2050, which will require a low-carbon energy system. This is particularly important if Ireland's relatively large agricultural sector is maintained, since this accounts for 30% of Ireland's greenhouse gas emissions [59].
4. The LCR already contains a unique energy infrastructure: the electricity transmission system and gas network is already well established throughout the region (see the E&EB for more details [13]).
5. It is possible to develop a new industry and brand for the LCR to maximise job creation, exports, and tourism.

Since the objective for the energy systems designed in this study will be structured under the framework of a 100% renewable energy system, there is one key limitation that needs to be considered before the energy scenarios in this study are defined: the biomass bottleneck.

4.1 The Biomass Bottleneck in 100% Renewable Energy Systems

Research to date has indicated that due to the flexibility of biomass (i.e. it exists in a solid, gas, and liquid form) as well as it similarities with fossil fuels (i.e. a stored transportable energy), it is very difficult to transition to a 100% renewable energy system without using more than the residual biomass resource available [19, 44]. This issue was previously highlighted in a bioenergy roadmap to 2050 by SEAI, in which the total forecasted demand for biomass (~7200 ktoe) was double the expected resource available (~3500 ktoe) [60]. It also became apparent once again while evaluating the renewable energy resource available in the LCR. If the renewable resources presented earlier in Figure 18 are categorised based on biomass, biogas, and intermittent renewable energy as displayed in Figure 19, it is clear that if the entire bioenergy resource is utilised in the region, it is approximately the same as the final energy consumption in 2020. In contrast, the IRES can potential cover 9 times the final energy consumption in 2020. Although the assumptions used to quantify the resource available are debateable, the magnitude of the difference suggests that IRES are substantially more abundant in the LCR than bioenergy resources. Hence, they should be prioritised to ensure that sufficient local resources are available for local energy demands and also to ensure that bioenergy is used sustainably with minimal impacts on food production and other agricultural products.

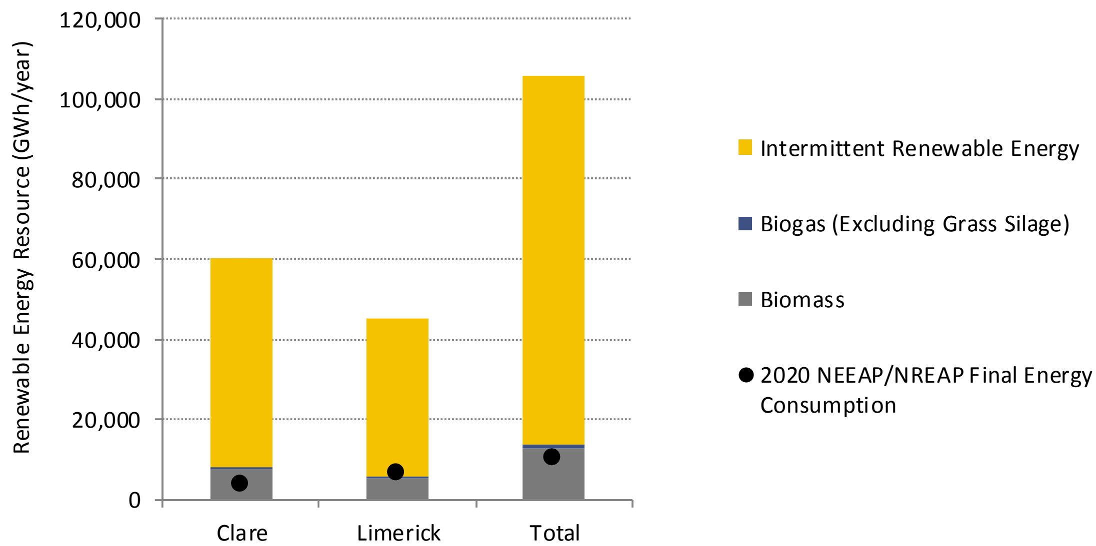

Figure 19: Renewable energy resource by type of fuel available in the LCR.

In addition, the land-area necessary to produce the same amount of energy from IRES and bioenergy indicates that IRES should be prioritised. As Figure 20 depicts, it requires approximately 5 to 50 times more land area to produce 1 PJ of energy from biomass than from wind energy. It is important to recognise that this are indicative values only, since often bioenergy can be created as a by-product of another process, and hence there may be no direct land-use change associated with the process. However, in the context of 100% renewable energy systems, it is evident from the biomass resource identified in the LCR (Figure 18), that bioenergy by-products will not be sufficient to cover all of the demands. This does not suggest that bioenergy should not be utilised, it simply highlights a key limitation associated with biomass when considering the long-term objective of a 100% renewable energy system.

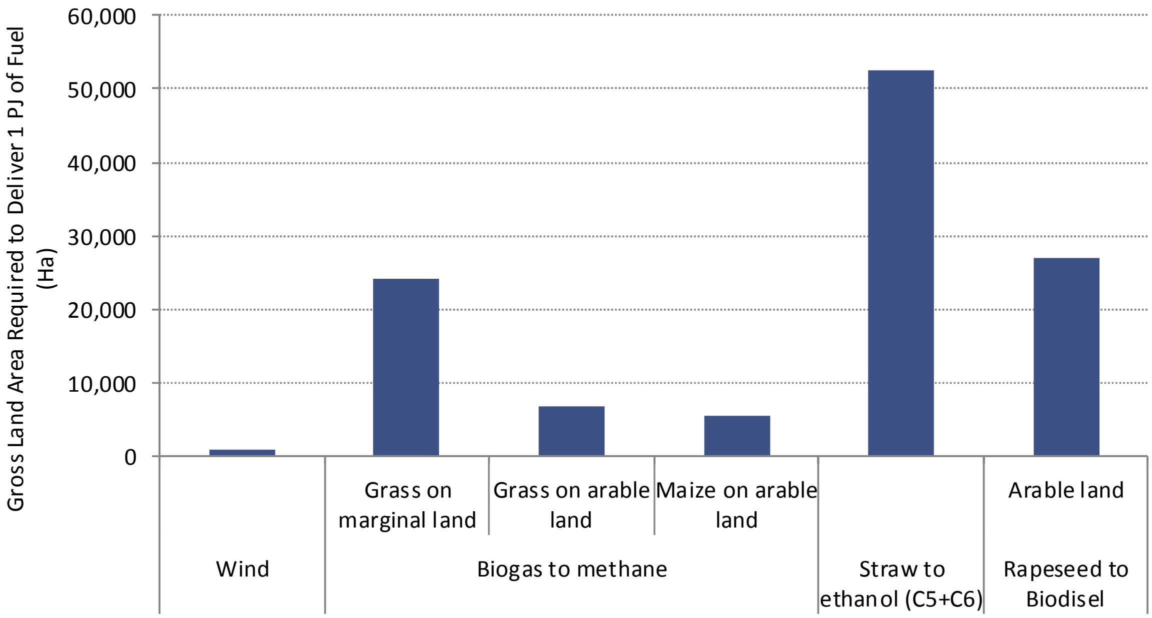

Figure 20: Gross land-area necessary to produce 1 PJ of wind generated electricity and a selection of biofuels [61-63].

Finally, it is also important to recognise that this biomass bottleneck is not unique for the LCR. As outlined in Figure 21, the global biomass resource estimated for the rest of the world is approximately 2-30 GJ/person. In contrast the biomass resource estimated for the LCR in this study is approximately 150 GJ/person: this is particularly high since it represents the maximum resource available and the LCR is a predominantly rural region. Nonetheless, if the LCR is going to be part of a 100% renewable energy Ireland or World, these metrics indicate that the region will need to consume even less than the biomass resource identified in this study. In other words, the problem will not be solved by simply importing bioenergy from elsewhere. Once again, the key message here is that bioenergy is a very valuable commodity in a 100% renewable energy system, but it is also necessary since it is the only combustible form of renewable energy available. Hence, the scenarios created in this study have been designed to reduce the use of the biomass resource where it is technically and economically viable.

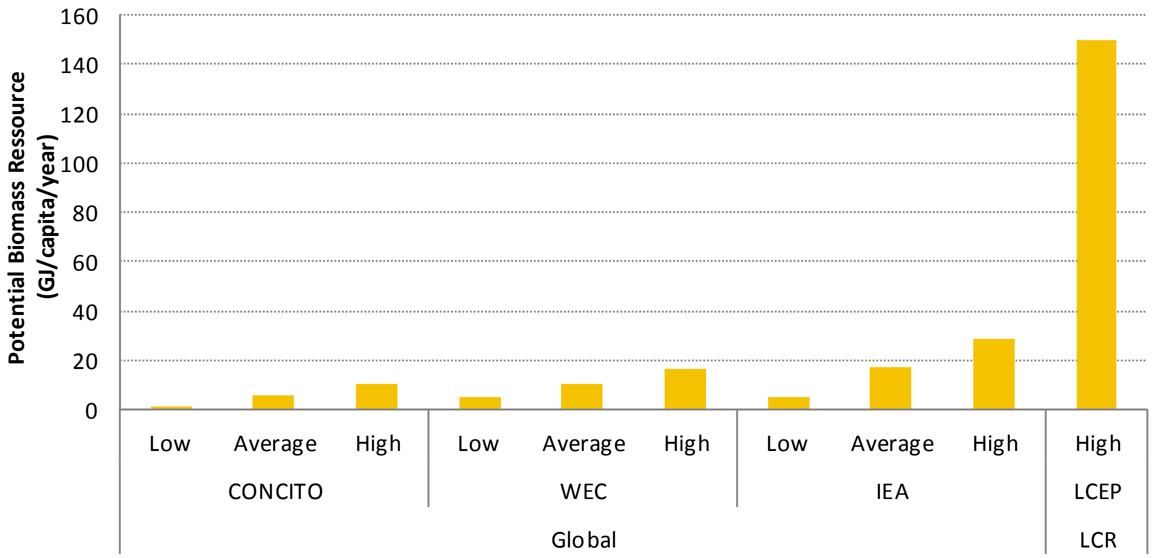

Figure 21: Comparison between estimates for the global biomass resource available for energy production [61, 64-66].

4.2 2020: Additional Actions for the Heat Sector

In 2020, four scenarios have been considered in total. Two of these have been taken from the energy forecasts projected by the Sustainable Energy Authority of Ireland (SEAI) [14]:

1. **Baseline:** The *Baseline* scenario "includes all policy measures legislated for up to the end of 2009 and represents a hypothetical future scenario in which no further policy actions or measures have been taken" [14]. In other words, the *Baseline* scenario represents what will occur under existing Irish government policies without any further actions.
2. **NEEAP/NREAP:** The *NEEAP/NREAP* represents a scenario where Ireland successfully implements its EU 2020 targets: 20% energy savings and 16% of primary energy supply coming from renewables. The steps necessary for 20% energy savings are outlined in the National Energy Efficiency Action Plan (NEEAP) [15], while the actions required to achieve a 16% renewable energy share in primary energy supply are outlined in the National Renewable Energy Action Plan (NREAP) [16]. Hence, the *NEEAP/NREAP* will illustrate the implications for the LCR if government policy is followed between now and 2020.

In addition, two further scenarios are presented in this study for 2020 to identify additional steps which can be taken in the LCR by 2020. Before describing them in detail, it should be noted that the design of the 2020 scenarios did not occur in isolation. It involved a lot of interaction between the scenarios also investigated in

2050 (which are discussed in more detail in section 4.3), to ensure that the short-term actions in the LCR fit with the long-term vision. For now however, the focus will be on 2020.

These two additional scenarios focused particularly on the heating sector for the following key reasons:

- When evaluating the *NEEAP/NREAP 2020* scenario, the authors deemed the actions in the electricity and transport sectors as adequate relative to the current range of technologies available, (this is discussed in more detail when the results are presented).
- Heating technologies based on renewable energy are already very well established and commercially available such as heat pumps, district heating, biomass boilers, and energy efficiency measures. As a result, actions identified for the heating sector can begin immediately.
- Actions within the heating sector typically do not interfere with actions underway elsewhere. For example, building additional IRES requires coordination across the entire national electricity grid, whereas changing an individual boiler can be carried out at a local level. Hence, the LCR can immediately begin the process of transforming the heat sector at a local level.
- The heating sector urgently needs a 'long-term lock-in' debate, particularly in relation to the gas grid. At present the gas grid is being expanded significantly in Ireland. However, in the long-term, this will lead to a very inflexible solution. In other words, if fossil fuels are eventually replaced by renewable energy, then natural gas will also need to be replaced. However, as already illustrated, the biomass resource is very limited in the future in comparison to the energy demands. Therefore, it is very unlikely that there will be enough bioenergy available to substitute the natural gas demand directly. In addition, other than bioenergy, there is no obvious renewable energy alternative for the gas grid, so by expanding it, the heating sector is being locked-in to one form of energy (gas) which is unlikely to have a renewable energy substitute. In comparison, heat pumps (HPs) can use a variety of different forms of electricity from renewables (i.e. wind, wave, PV, tidal) and district heating (DH) can use a variety of sustainable heating sources (i.e. CHP, heat pumps, surplus industrial heat, solar thermal, geothermal). Hence, these are much more flexible solutions.

Based on these principles, two new heating scenarios were developed for the LCR using the exact same demands as the *NEEAP/NREAP* scenario. These scenarios are primarily based on district heating (DH) and heat pumps (HPs), since previous research has suggested that these are the most efficient and cost effective heating technologies currently available [67-69]. The two additional scenarios constructed for 2020 are:

3. **DH&HP:** In this scenario, all actions in the *NEEAP/NREAP 2020* are carried out, but with two key changes in the heating sector. Approximately 12,000 urban households are converted from fossil fuel

boilers to district heating: this is approximately 25% of urban households in the LCR. In addition, approximately 13,000 rural households are converted from fossil fuel boilers to ground-source heat pumps. To supply the heat necessary for the district heating network, natural gas CHP plants and boilers are constructed. Ideally, surplus industrial heat in the region would be utilised, but after discussing this with large energy users in the region, it was unclear if the technology could be established by 2020. Since natural gas is used for CHP and centralised boilers in this scenario, there is no additional renewable energy added compared to the *NEEAP/NREAP 2020* scenario. Hence, the *DH&HP* scenario only illustrates the consequences of moving to a more energy efficient system.

4. **LCR 2020 (DH&HP+RE):** This is the scenario that is recommended for the LCR by 2020. All actions described in the *DH&HP* scenario are repeated here, but renewable energy is also expanded as follows:
    a. 50% of the biogas potential in the region from animal (slurry and manure) and organic by-products (460 GWh) is used by 2020 to replace natural gas. Costs and losses have been included for upgrading the biogas to natural gas quality, but if it is used in decentralised CHP plants, then these may be avoided. Since this biogas is predominantly from waste materials, direct land-use changes should be relatively low.
    b. 5% of the heat demand is met by individual solar thermal units.
    c. 15% of the district heating demand is met by centralised solar thermal systems.
    d. 25 MW of PV is added since a variety of different renewable resources is beneficial for the integration of more IRES and the cost of PV is expected to drop rapidly in coming years. For example the costs are expected to drop by 40% in the next five years (from 3.5 M€/MW in 2010 [11] to 2 M€/MW in 2015 [6]).
    e. 10 MW of tidal energy is added since OpenHydro [70], who are located in Ireland, is one of the world's leading tidal manufacturers and is already installing tidal farms worldwide. Wave power was not included since there is still uncertainty surrounding the development of the technology, but if it becomes commercially viable it should also be considered.
    f. Heat pumps are added to the district heating system to use excess IRES.

    As a result, this scenario will demonstrate the impacts of adding more renewable energy sources to the new efficient energy system created with DH and HPs.

Finally, before presenting the results, a breakdown of the key inputs for all four 2020 scenarios created is presented in Table 4, while a more detailed breakdown is available in Appendix IV.

Table 4: Key technical inputs for the 2020 scenarios considered in this study: a more detailed breakdown is available in Appendix IV.

Sector	Input	2020 Scenarios			
		Baseline	**NEEAP/NREAP**	**DH&HP**	**LCR 2020 (DH&HP+RE)**
Power Plants and District Heating	Condensing Power Plants (MW)	446	479	473	478
	DH Demand (TWh)	0	0	0.198	0.198
	CHP (MW)	0	0	65	65
	Thermal Storage (GWh)	0	0	5.21	5.21
	Heat Pump (MW)	0	0	0	5
	Boiler (MW)	0	0	89	89
	Solar (TWh)	0	0	0	0.018
	Solar Storage (GWh)	0	0	0	0.390
Intermittent Renewable Electricity Sources	Wind (MW)	184	330	330	330
	Hydro (MW)	86	86	86	86
	PV (MW)	0	0	0	25
	Wave (MW)	0	0	0	0
	Tidal (MW)	0	0	0	10
Individual Heating	Coal Input (TWh)	0.173	0.155	0.109	0.109
	Oil Input (TWh)	1.392	0.973	0.682	0.682
	Natural Gas Input (TWh)	1.036	0.691	0.484	0.484
	Biomass Input (TWh)	0.038	0.134	0.134	0.134
	Heat Pump Heat Demand (TWh)	0.007	0.023	0.250	0.250
	Electric Heating Heat Demand (TWh)	0.289	0.268	0.201	0.201
	Solar Heat Production (TWh)	0.002	0.007	0.007	0.094
Electric Vehicles	Electricity Smart Charge (TWh)	0	0.031	0.031	0.031
	Grid to Battery Connection (MW)	0	76	76	76
	Battery Storage Capacity (GWh)	0	0.38	0.38	0.38
	Number of EVs	0	15,000	15,000	15,000
Biofuels	Biogas (TWh)	0	0	0	0.459
	Biodiesel (TWh)	0.08	0.226	0.226	0.226
	Bioethanol (TWh)	0.034	0.097	0.097	0.097

4.2.1 Results for 2020

Once these scenarios were defined, they were simulated in EnergyPLAN to quantify their impacts in terms of primary energy supply (PES), renewable energy production, annual socio-economic costs, job creation, and balance of payment.

As outlined in Figure 22, the PES in the *Baseline* scenario is approximately 10% higher than in the *NEEAP/NREAP* scenario, which is due to the energy savings and higher conversion efficiencies of the technologies in the *NEEAP/NREAP* scenario. Furthermore, the CO_2 emission reductions in the *NEEAP/NREAP* are even greater at ~20% below the *Baseline* scenario. This additional saving is most likely due to the increased renewable energy penetrations in the *NEEAP/NREAP* scenario: as displayed in Figure 23, the renewable energy penetration almost doubles in the *NEEAP/NREAP* scenario compared to the *Baseline*. This indicates that the LCR will reduce its energy demand and its CO_2 emissions if the actions proposed in NEEAP and NREAP are implemented. Hence, the authors recommend that these initiatives are followed, with the only key concern in relation to the use of biomass, particularly for biodiesel and bioethanol: it is important to ensure that the biomass resource is used in a sustainable way as discussed in section 4.1.

Proceeding to the new alternatives proposed in this study, the results indicate that if the LCR takes the additional steps of implementing DH in the urban areas and HPs in the rural areas (*DH&HP* scenario), the overall efficiency of the energy system will be increased even further: Figure 22 portrays an overall drop in the PES and CO_2 emissions of approximately 6% in the *DH&HP* scenario compared to the *NEEAP/NREAP* scenario. However, as explained earlier when defining the scenarios, and as displayed in Figure 23, no additional renewable energy has been added in the *DH&HP* scenario compared to the *NEEAP/NREAP* scenario. Hence, the PES and CO_2 emissions reductions are solely due to overall energy efficiency improvements which occur since:

1. A combination of CHP plants and district heating is more efficient than a combination of condensing power plants and individual boilers.
2. Heat pumps are more efficient than electric heating or fossil fuel boilers.

However, it is also possible for the LCR to implement the *DH&HP* scenario along with more renewable energy while still maintaining these efficiency improvements. This is demonstrated in the *LCR 2020* scenario: Figure 22 verifies that there is practically no change in the overall PES between the *DH&HP* and the *LCR 2020* scenarios, while at the same time Figure 23 indicates that the overall renewable energy production has been increased by approximately 30%. As a result, if the LCR implements the *LCR 2020* scenario, the share of renewable energy in the electricity sector will be approximately 70%, while the share of renewable energy in the PES will be approximately 25%. This is significantly more than the national targets of 40% and 16% respectively, thus creating a low-carbon brand for the LCR.

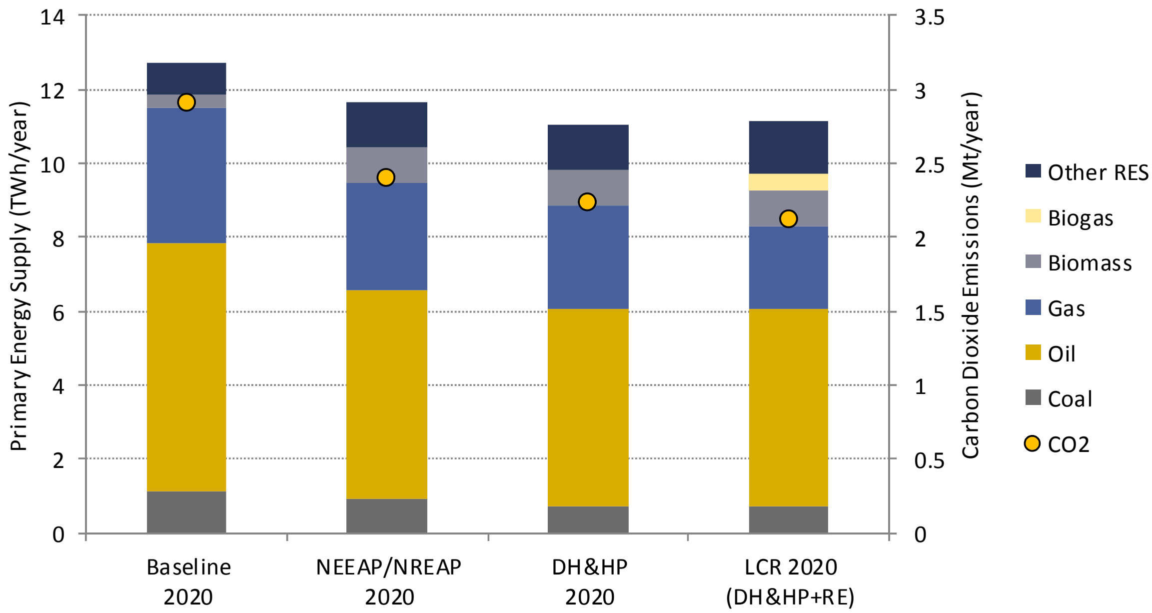

Figure 22: Primary energy supply and CO_2 emissions for the 2020 scenarios considered.

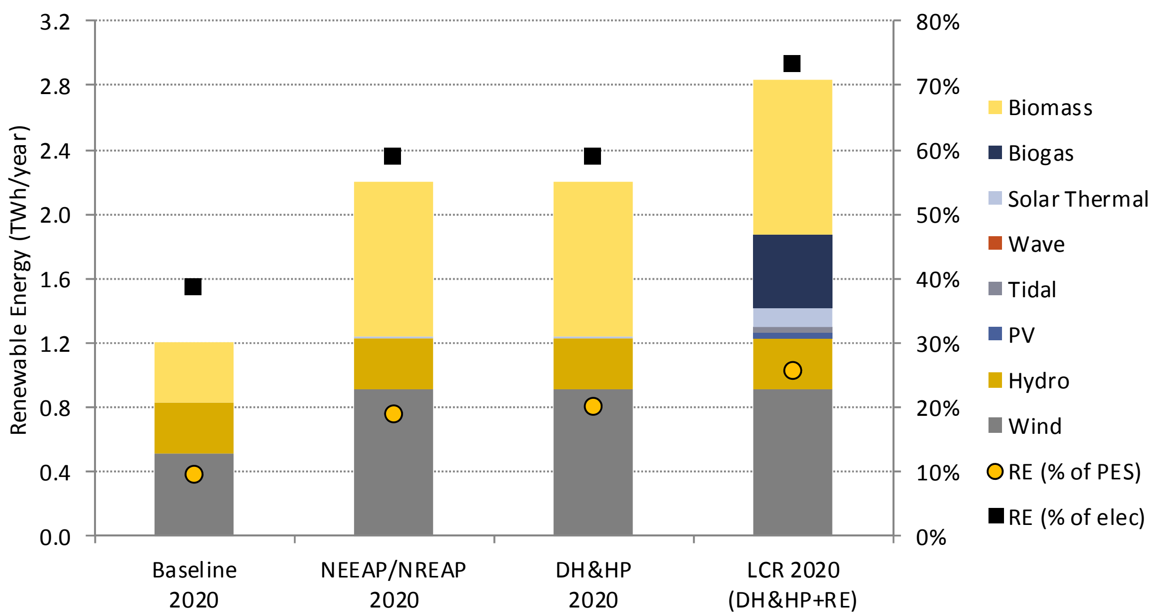

Figure 23: Renewable energy production and penetrations for the 2020 scenarios considered.

Considering these significant infrastructural changes, it is naturally important to assess the resultant costs, which are displayed in Figure 24. These are the annual costs of providing energy in the LCR under the various scenarios proposed using forecasted 2020 investment costs, which are provided in Appendix II, and an interest rate of 3% to annualise the investments. Also, the fuel prices used reflect an oil price of $107/bbl and the CO_2 price is $25/t: these are the predicted fuel and CO_2 prices for 2020 [7, 28], although it should be noted that the average monthly price of crude oil in 2012 so far (January to May) is $111/bbl [71]. Therefore, a $107/bbl forecast for 2020 is conservative.

Using these assumptions, the results in Figure 24 indicate that the annual costs of the *Baseline* are approximately 10% more than those in the *NEEAP/NREAP* scenario. Hence, the actions identified in the NEEAP and NREAP will not only reduce the energy demand and increase renewable energy production, but it will also decrease the cost of operating the energy system. Furthermore, results indicate that the *DH&HP* and *LCR 2020* scenarios cost approximately the same as the *NEEAP/NREAP* scenario: the exact differences are 1% less and 2% more respectively, which was deemed close enough to be considered the same. This indicates that the additional energy efficiency and renewable energy achieved in these scenarios does not come with a significant additional cost.

Finally in relation to the annualised costs, there is a crucial trend that can be demonstrated in Figure 24: as the LCR moves from a traditional fossil-fuel energy system to a sustainable energy system, the type of expenditure will change dramatically from a fuel-based system to an investment-based system. This is evident when the level of investment in the *LCR 2020* scenario is compared to the *Baseline* scenario: investments increase by approximately 75% (60 M€/year), while fuel costs drop by approximately 25% (128 M€/year). This creates a unique opportunity for local job creation, since money is now being invested in local actions (such as savings, conversion technologies, and production units) instead of importing fuels.

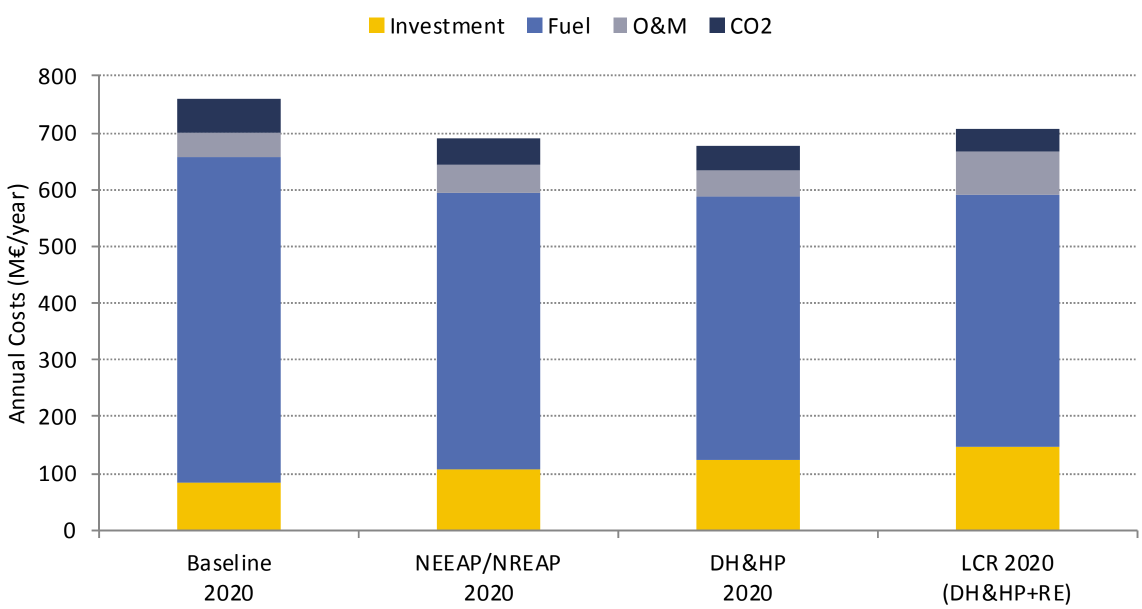

Figure 24: Socio-economic costs using 2020 investment costs, fuel prices, and CO_2 price for the 2020 scenarios considered.

To estimate the number of additional jobs created in the LCR, Danish import shares for different types of energy expenditure have been used [19, 20]. The import share estimates the proportion of a cost which is spent on salaries outside of a region, while the remainder is spent on salaries within the region. Assuming an average annual salary in Ireland of €45,000 [72], the result in Table 5 indicate that in comparison to the *Baseline* scenario, the *NEEAP/NREAP* scenario will create approximately 550 extra jobs, the *DH&HP* scenario approximately 850 extra jobs, and the *LCR 2020* scenario will create almost 2000 extra jobs in the LCR. This is due to the transition from an importing-fuel based system to a local-investment based system. It is worth noting that this does not account for indirect jobs such as those created in shops and restaurants (which SEAI estimates is approximately 15% more [73]), nor does it account for the additional jobs created due to exports from the region with the development of new technologies and industries (which can be multiples of this [74]).

In summary, if the *LCR 2020* scenario proposed in this study for 2020 is implemented instead of a business-as-usual *Baseline* scenario, then the LCR will:

- Reduce its demand for energy by approximately 12%
- Increase the production of local renewable energy to 70% of electricity and 25% of primary energy supply
- Reduce its CO_2 emissions by approximately 30%
- Reduce the cost of energy in the region by approximately 7%
- Create almost 2000 additional local jobs

However, considering the long-term lock-in associated with energy infrastructure (see Figure 13), the final key issue is to ensure that these actions fit with a long-term objective of becoming 100% renewable energy in the region. In this study, it is proposed that the year 2050 is set for this target and so the following section demonstrates how the Limerick-Clare energy system will evolve to 2050 based on DH in the urban areas and HPs in the rural areas.

Table 5: Estimated additional jobs created between 2013 and 2020 compared to the *Baseline* scenario if the *NEEAP/NREAP*, *DH&HP*, *LCR 2020 (DH&HP+RE)* scenarios are implemented by 2020.

Annual Job Creation 2013-2020 ($107/bbl & $25/t CO_2)											
Cost (M€/year)	**Total Cost Difference to the Baseline Scenario**			**Import Share [19, 20]**	**Money Spent Creating Jobs (M€/year)**			**Average Salary [72]**	**Additional Jobs vs. Baseline**		
	NEEAP/NREAP	**DH&HP**	**LCR 2020**		**NEEAP/NREAP**	**DH&HP**	**LCR 2020**		**NEEAP/NREAP**	**DH&HP**	**LCR 2020**
Investments	46	94	138	60%*	18	38	55	€45,000	407	835	1,223
O&M	4	2	30	20%	3	2	24		71	36	533
Fossil Fuel	-99	-125	-158	90%	-10	-13	-16		-220	-278	-351
Biomass Fuel	14	14	29	10%	13	13	26		280	280	580
Total	-35	-15	39		24	39	89		538	873	1,986

***An import share of 40% was previously used on investments in Denmark [19, 20], but this was increased to 60% for the LCR since Ireland's energy sector is not as well established as Denmark's.**

4.3 2050: 100% Renewable Energy

For 2050, only one 'reference' scenario is considered: the ***NEEAP/NREAP 2050*** scenario. This was created by projecting the *NEEAP/NREAP 2020* scenario forward to 2050 by assuming the same growth rates as observed between 2010 and 2020. A detailed breakdown of the resulting energy demands for the *NEEAP/NREAP 2050* scenario is available in Appendix III. This will act as a business-as-usual 'fossil fuel' scenario to 2050, which acts as a benchmark when evaluating a 100% renewable energy system for the region.

As discussed in section 2.2.1, EnergyPLAN has previously being used to analyse a wide range of studies focusing on 100% renewable energy systems. Therefore, the type of 100% renewable energy system analysed for the LCR is defined based on the typical results and technologies identified during this previous research. The key guidelines applied are:

1. Since there is an abundant supply of IRES in the LCR, a wide variety of wind, wave, solar, and tidal capacities could potentially be considered. To reduce the number of scenarios, it is assumed here that at least 90% of the electricity produced from intermittent resources must be integrated onto the energy system. If more than 10% of the electricity generated by IRES is curtailed, then it is usually not economically to add more IRES capacity to the system. Using this guideline a single IRES capacity can be defined for each 100% renewable energy scenario simulated rather than considering a wide variety of different capacities.
2. The biomass demand will be minimised where possible to avoid using more than the potential resource available, to reduce land-use changes, and to limit the impact on food production (see section 4.1) [44].
3. In Denmark, previous research has indicated that the most economical 100% renewable energy system uses district heating where the heat density is sufficient and uses heat pumps outside of the district heating areas [67-69]. However, since Ireland doesn't have any district heating to date, heat pumps may be an alternative option to district heating. To account for this, a scenario is considered in this study where heat pumps are used in both urban and rural areas.
4. Electricity storage is usually not an economic addition to an energy system [45, 48]. Energy storage has two principle roles in a renewable based energy system: (a) contributing to grid stability and (b) storing surplus intermittent electricity production.
    a. In relation to grid stability, existing energy systems are primarily based on large centralised power stations which are not very fast at ramping up or down in response to variations in intermittent renewable resources. Since energy storage facilities such as pumped hydroelectric energy storage (PHES) are very good at this, they are an ideal way of

accommodating both types of technologies. However, in the future energy system where decentralised production is expanded to use local renewable resources (such as biogas and biomass), there is no longer just a few centralised power plants, but instead there may be hundreds of decentralised power plants. This transition has already begun in the Danish electricity network, which is evident from the number of decentralised CHP plants in Figure 25. In this future decentralised system, power plants will be able to regulate faster and potentially accommodate fluctuating renewable energy without the need for energy storage as an accommodating technology: for example, from 03:00-04:00 on the 12th of May 2012, approximately 76% of electricity production in Denmark was from wind turbines even though there is no energy storage [75]. Furthermore, in the future energy system the demand side will also be able to contribute to grid stability (as illustrated by an electric boiler in Lund *et al.* [76]) and fluctuating renewable energy technologies may be able to contribute to grid stabilisation. Therefore, the need for grid stability is still unclear. Considering the lifetime of large-scale energy storage is approximately 50 years, it is thus very risky to invest in PHES at present.

b. In relation to surplus intermittent electricity production, the key challenge for energy storage is operating time. There are relatively few hours in the year when excess electricity is available to charge a PHES facility and when power plant production can be replaced to discharge a PHES facility [45]. Since the initial investment for energy storage is relatively high, it is usually not economical to build such a facility unless the number of operating hours increases.

These previous observations are difficult to directly apply to the LCR and hence, energy storage will be considered in a sensitivity analysis during this study.

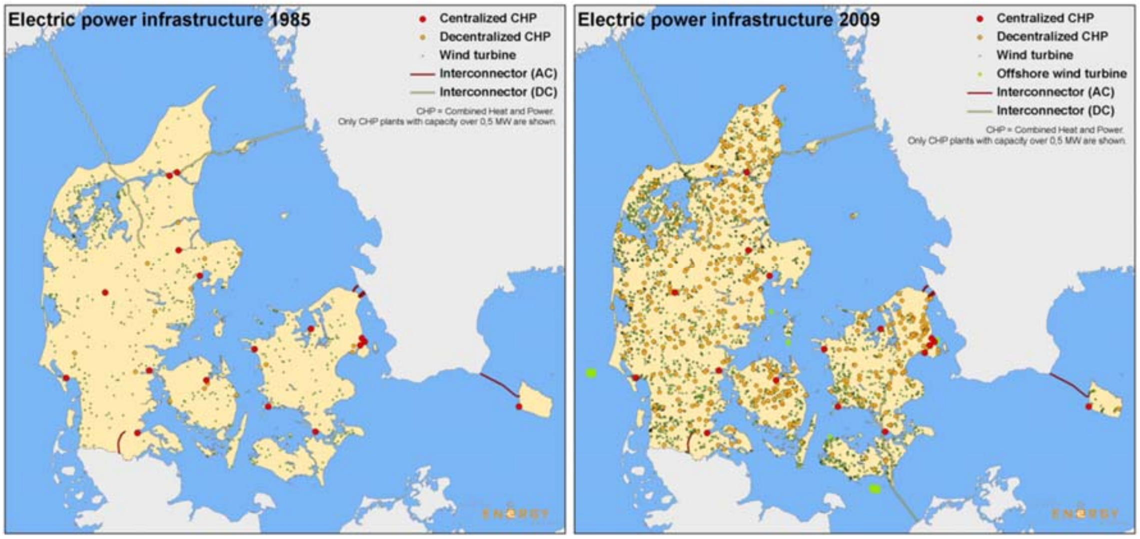

Figure 25: Electricity infrastructure in Denmark in 1985 and 2009 [77].

5. Electric vehicles (EVs) should be prioritised as much as possible to reduce the demand for biomass-based gas or liquid fuels [44]: it is assumed here that EVs can cover up to 75% of the transport demand for private cars (similar to SEAI's forecast of 70% [78]).
6. Transport fuels which cannot be provided using electricity should use a combination of CO_2 (which can be from bioenergy) and hydrogen to create synthetic fuels [44]. This will ensure that a cost-effective energy system is still viable while the biomass demand is minimised [44]. To date, it is not clear what exact source of CO_2, bioenergy, and hydrogen will be used, since there are a number of options such as biogas hydrogenation, biomass hydrogenation, CO_2 hydrogenation and co-electrolysis. Therefore, any pathway chosen in this study will simply act as a proxy and will be updated as more knowledge is generated in this area. As a result, the biomass hydrogenation pathway for creating methanol or DME, which was created in a previous study [44], has been used here to ensure that the liquid fuel demands in 2050 are met. The additional vehicle costs for methanol and DME have also been accounted for and are outlined in Appendix II.
7. Energy savings are a vital component of future energy systems and are often the most economic actions to implement [79]. Since these measures are included in the *NEEAP/NREAP 2020* scenario, which was used as the basis for projecting the *NEEAP/NREAP 2050*, it is assumed that energy efficiency is already accounted for. Hence, no additional measures have been added, even though it is possible that even more measures can be economically implemented.

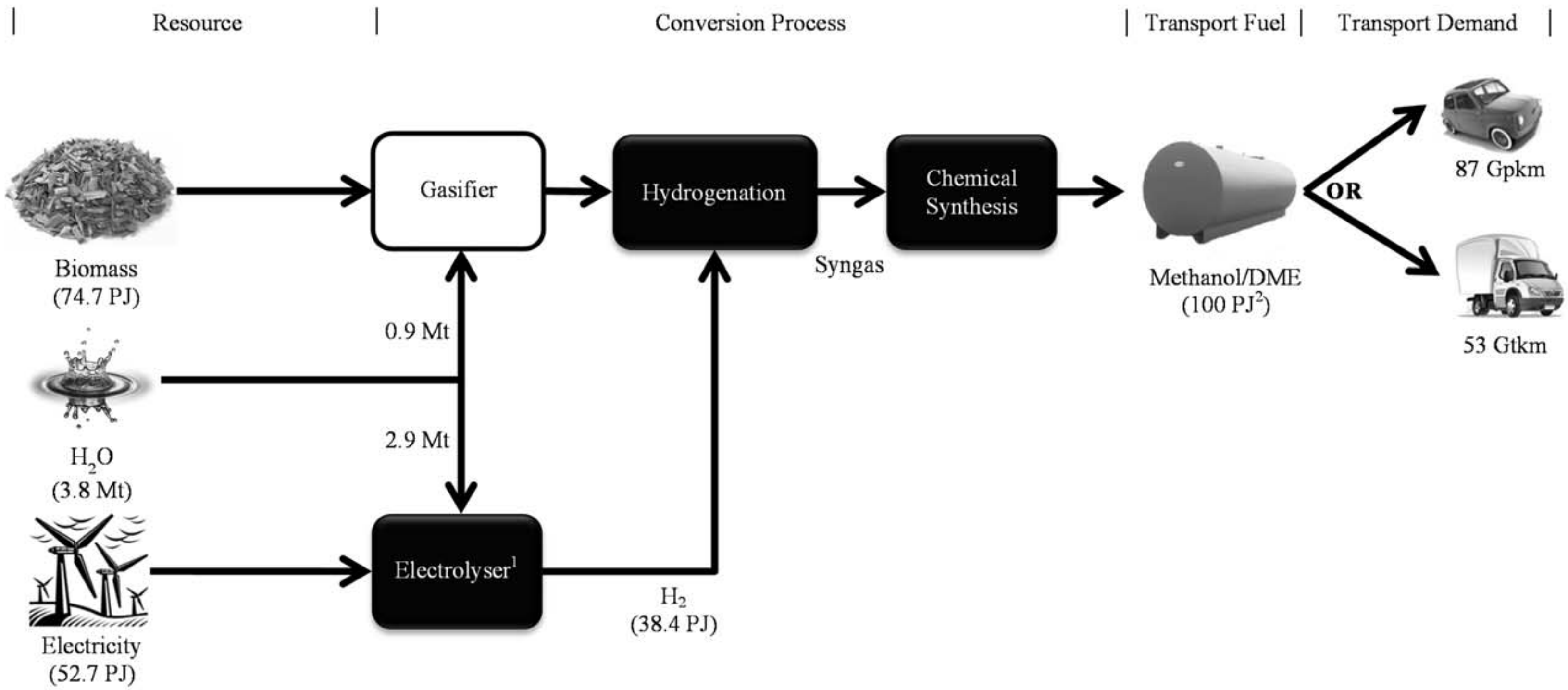

Figure 26: Gasification of biomass which is subsequently hydrogenated. [1]Assumed an electrolyser efficiency of 73% for the steam electrolysis [19]. [2]A loss of 5% was applied to the fuel produced to account for losses in the electrolyser, chemical synthesis, and fuel storage [80].

Based on these key experiences, nine alternative 100% renewable energy systems were considered for the LCR in 2050, which considered various mixes of district heating, heat pumps, and energy storage (in the form of PHES and hydrogen). These are described and compared in Appendix V. The key results from this comparison are as follows:

1. District heating or air-to-water heat pumps in urban areas results in an equally efficient energy system, but district heating is a cheaper alternative.
2. Energy storage can reduce the biomass demand without an increase in costs, but hydrogen storage is a more promising alternative than PHES.

This verifies that if the LCR invests in a mix of district heating and heat pumps between now and 2050, it will contribute to a 100% renewable energy vision. This is illustrated in the **LCR 2050 (DH&HP+RE&H2)** scenario in Appendix V, which assumed that all urban households (~50,000) in the LCR would convert to district heating and all rural houses would install a heat pump (~50,000). In addition, 75% of private vehicles are electric and the remaining demand for transport is supplied using liquid fuels (methanol/DME) from biomass hydrogenation (see Figure 26). A full breakdown of the demand and supply for this scenario can be seen in Appendix VI. Next, this *LCR 2050* scenario will be compared to the business-as-usual *NEEAP/NREAP 2050* scenario to quantify the consequences of transitioning to a 100% renewable energy system.

4.3.1 Results for 2050

In this section, the business-as-usual *NEEAP/NREAP 2050*, which is based on fossil fuels, is compared with a 100% renewable energy scenario called *LCR 2050*, which was deemed the most sustainable alternative from all of the 100% renewable energy scenarios considered in Appendix V. Although the analysis has been carried out with the same level of detail as the 2020 analysis, there is naturally a much greater degree of uncertainty due to the level of change being proposed and the potential changes that can occur over the timeline in question. However, the results are equally valuable since they identify some additional challenges which would otherwise go unnoticed with a short-term optimisation.

The first results are once again the PES. As outlined in Figure 27, the 100% renewable energy system requires approximately 8% less energy than the fossil fuel reference scenario. Once again, this is primarily due to more efficient conversion technologies (such as district heating, heat pumps, and electric vehicles), since the end-user demands are the same in both scenarios. Furthermore, as displayed in both Figure 27 and Figure 28, the biomass in the 100% renewable scenario is approximately 7 TWh (excluding biogas, which has been limited to the resource available from waste products). According to the renewable energy resource assessment (Appendix VIII), there is a maximum potential biomass resource of ~13 TWh in the LCR. This means that if this

100% renewable energy scenario proposed is to be realised, then 55% of the potential biomass resource in the region will need to be utilised. Since this would require one third of the land area of the region (~140,000 Ha), it is highly unlikely that this can be implemented without significant land-use change, again outlining the concerns with excessive biomass consumption. However, one additional step which has not been explored in this study is the conversion of the industrial demands in the region from fuel to electricity, so more IRES could be used instead. Since industry accounts for 2.75 TWh of the biomass consumption, this could reduce the demand significantly.

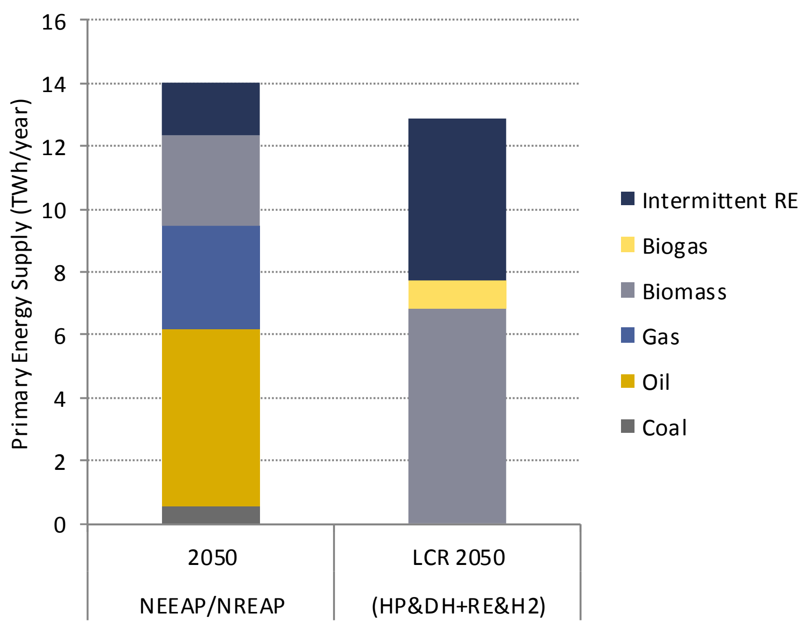

Figure 27: Primary energy supply and CO_2 emissions for the 2050 scenarios considered.

The other renewable resources consumed in both scenarios are outlined in Figure 28. After biomass, wind power is the used the most due to its cost and current stage of development. Other forms of IRES have been introduced since previous research has indicated that a combination of different IRES is easier to integrate than one single source [81], but these exact capacities are not based on any specific criteria.

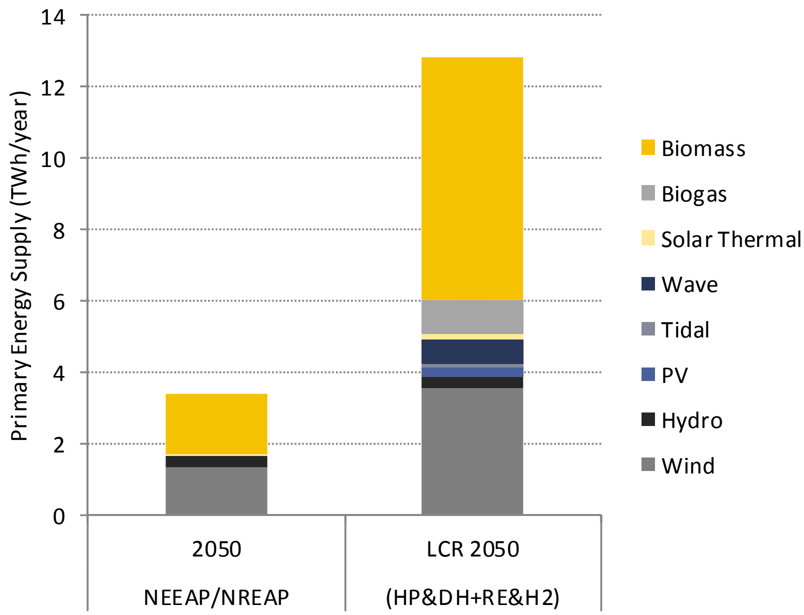

Figure 28: Renewable energy production and penetrations for the 2050 scenarios considered.

Looking at the annual costs, Figure 29 indicates that the 100% renewable energy scenario is approximately 14% more expensive than the fossil fuel alternative based on 2020 investment costs, fuel prices, and CO_2 cost. However, to illustrate the sensitivity of each scenario to increased fuel and CO_2 costs, the analysis was repeated using fuel prices which reflect an oil price of \$142/bbl and a CO_2 price of \$50/t: these are projected fuel prices for 2050 based on forecasted trends to 2030 (see Appendix II for more details). These demonstrate the sensitivity of each scenario to the forecasted increases in fuel prices over the lifetimes of the technologies included. Ideally, 2050 investment costs should also be used with the 2050 fuel price scenario, but it was not possible to create this database within the timeframe of this study. Nonetheless, the result here indicate that the 100% renewable energy alternative is reasonably robust to changes in fuel prices since the overall costs only rise by 5% when fuel prices increase from 2020 levels to 2050 levels. In contrast the fossil fuel based system is very sensitive to fuels prices, since the overall costs rise by 25% for the fuel price increases. As already discussed in section 4.2.1, this occurs because renewable energy systems are primarily based on investments whereas fossil fuel based systems are primarily based on fuels. In line with this, since investment costs are likely to decrease between 2020 and 2050, while conversely fuel prices rise, it is likely that under existing forecasts the 100% renewable energy (*LCR 2050*) will be cheaper in 2050 than the fossil fuel based system (*NEEAP/NREAP 2050*).

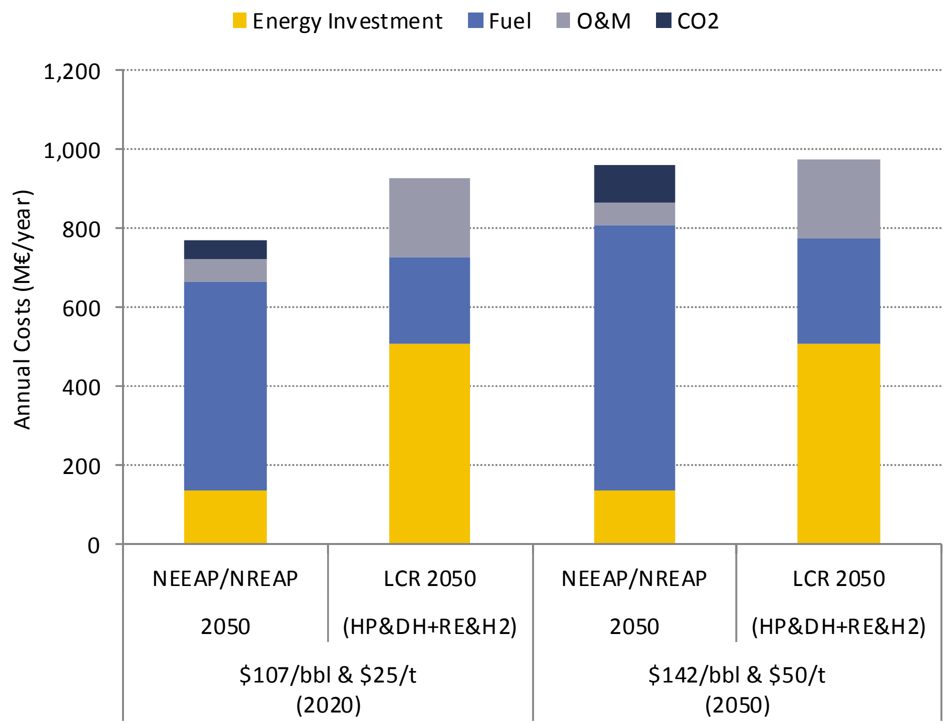

Figure 29: Socio-economic costs using 2020 investment costs and two different fuel price scenarios (2020 and 2050) for the 2050 scenarios considered.

Similar to the methodology used for 2020 in section 4.2.1, the annual job creation for the both 2050 scenarios has also been estimated here. As outlined in Table 6, the 100% renewable energy scenario will create approximately 275% more jobs in the LCR than the fossil fuel system. Some jobs will be lost in the fossil fuel industry, but counter increases in technology (i.e. investments), O&M, and biomass will more than compensate for this so that overall there will be an average of approximately 12,500 directly employed in the energy sector in the LCR if a 100% renewable energy system is implemented. Once again this this does not account for indirect jobs such as those created in shops and restaurants (which SEAI estimate is approximately 15% more [73]), nor does it account for the additional jobs created due to exports from the region with the development of new technologies and industries (which can be multiples of this [74]).

Table 6: Estimated annual jobs created in the LCR for the fossil fuel (*NEEAP/NREAP 2050*) and 100% renewable energy system (*LCR 2050*) in 2050.

Job Creation ($107/bbl & $25/t CO_2)								
Cost (M€/year)	**Annual Investments (M€/year)**		**Import Share* [19, 20]**	**Money Spent Creating Jobs (M€/year)**		**Average Salary**	**Local Jobs Created**	
	NEEAP/ NREAP 2050	**LCR 2050**		**NEEAP/ NREAP 2050**	**LCR 2050**		**NEEAP/ NREAP 2050**	**LCR 2050**
Investments	135	510	60%	55	205	€45,000	1,200	4,500
O&M	60	200	20%	45	160		1,000	3,600
Fossil Fuel	465	0	90%	45	0		1,000	0
Biomass Fuel	65	220	10%	60	195		1,350	4,350
Total	725	930		205	560		4,550	12,450

***An import share of 40% was previously used on investments in Denmark [19, 20], but this was increased to 60% for the LCR since Ireland's energy sector is not as well established as Denmark's.**

Finally, since these jobs are created locally, there is a very positive affect on the balance of payment for the region. In fact, if the fossil fuel based system is implemented, then approximately M€300 will leave the region each year to ensure the energy demands are met. In contrast, if the 100% renewable energy scenario is implemented, then a surplus of almost M€200 will stay in the region, since the energy demands are being met using local resources. This is a gain of almost M€500/year for the region. Therefore, even if the 100% renewable energy system turns out to be more expensive than the fossil fuel based system, it is highly probable that the local benefits will still be more substantial than in the fossil fuel based system.

Table 7: Balance of payment for the LCR the fossil fuel (*NEEAP/NREAP 2050*) and 100% renewable energy system (*LCR 2050*) in 2050.

Balance of Payment				
Cost (M€/year)	**NEEAP/NREAP 2050**		**LCR 2050**	
	Inflow	**Outflow**	**Inflow**	**Outflow**
Investments	54	-82	204	-306
O&M	46	-11	162	-40
Fossil Fuel	47	-419	0	0
Biomass Fuel	60	-7	195	-22
Total	207	-518	561	-368
	Net	**-311**	**Net**	**193**

In summary, the 2050 comparison has revealed a number of critical issues:

- Implementing the *LCR 2020* scenario will contribute towards the long-term objective of achieving a low-carbon 100% renewable energy system.
- The biomass bottleneck has appeared since even though every effort has been made to reduce the need for biomass, approximately one third of the land in the LCR would be required to create the resource necessary in a 100% renewable energy system. Therefore, a biomass strategy should be created in the region quantifying the residual resource available and further research will be necessary to identify how the biomass demand in this study can be reduced. In addition, actions relating to the use of biomass from resources which affect land-use should be approached with caution, even between now and 2020. For example, biomass being consumed in power plants (i.e. for co-firing), individual biomass boilers, biodiesel, and bioethanol should ideally be by-products of another process and not require the direct transformation of land. Since this will not always be possible, a regional biomass strategy will be essential to ensure that the short-term allocation of biomass resources contributes to a sustainable future energy system.
- Based on the likely increase in fuel and CO_2 prices along with a decrease in investment costs, a 100% renewable energy system will most likely be a cheaper alternative in 2050 than a fossil fuel based system while providing the same end-user demands.
- Since the 100% renewable alternative is based on local resources and local actions, there all be approximately 275% more energy-related jobs in the region, with an average of 12,500 people directly employed in the energy sector if a 100% renewable energy system is implemented.
- Even if the projected forecasts for the costs considered are incorrect and 100% renewable energy systems become more expensive than the fossil fuel reference scenario, the number of additional local jobs created is so significant that the overall balance of payment for the region is still likely to improve.

4.4 Common and Uncertain Actions towards 100% Renewable Energy

The scenarios developed in this study are only a snapshot in time and will be subject to repeated improvements as further research is carried out. Therefore, to conclude, below is a list of technologies which are certain to contribute to a sustainable energy system in the future:

1. Energy efficiency
2. Onshore wind turbines
3. Photovoltaic

4. Electric vehicles
5. Public transport
6. Heat pumps in rural areas
7. Biogas from waste resources
8. District heating in urban areas
9. Large-scale solar thermal
10. Surplus heat for district heating from power plants (i.e. CHP) and industry.
11. Heat pumps for district heating

While this is a list of technologies which may contribute to a sustainable energy system in the future, but the scale of implementation is still subject to technology developments and debate:

1. How grid stabilisation will be maintained in the future
2. The quantity of biomass relating to direct land-use change that should be used and also, where it should be used
3. Wave power
4. Tidal power
5. Passive housing
6. Pumped hydroelectric energy storage
7. The pathway towards liquid or gas fuels for transport
8. Electrolysers to boost biomass
9. What type of gas the gas grid will be used for

Therefore, by focusing on the technologies which are deemed certain between now and 2020, the LCR will be contributing towards a long-term sustainable scenario. Hence, all of the additional actions proposed in the *LCR 2020* scenario only include technologies from this list. However, since district heating will require a significant investment in the LCR, but it is not yet a mainstream technology in Ireland, the following section will discuss this technology in more detail.

5 District Heating

District heating is a facilitation technology which enables consumers to share heating costs. It was first established in New York in 1877, while the largest network worldwide is currently in Moscow (which supplies around 100 TWh of heat [82] to approximately 10 million people). However, to date, it has not been widely utilised in Ireland and so this chapter will try to outline what it is, how it benefits the energy system, and why it should be implemented in private homes instead of a gas network.

Historically, three primary forms of district heating have been established:

1. **Nordic:** District heating is widely used in Sweden, Iceland, Finland, and Denmark. These systems are mostly based on hot water with a supply temperature below 100^{O}C. It is the most efficient type of system developed and primarily utilises pre-insulated piping. Also, these systems vary the flow rate to control temperature instead of using large pipes.
2. **Central Europe:** Consists of many large industrial consumers with high supply temperatures that reach up to 250^{O}C: as a result, the pipes are relatively large. These systems have mostly been installed by private companies on a commercial basis.
3. **Eastern Europe:** These systems have no temperature controls in individual houses since everyone is connected in series (i.e. if one person switches off the heat, then everyone's heat is switched off). These systems typically use steam at a supply temperature of 130-150^{O}C. There is no obvious reason for designing DH in this way.

For the LCR, the Nordic district heating system will be the most suitable since the focus is on efficiency. Furthermore, since it will be a new district heating network, it should be a low-temperature system (40-60^{O}C), so low-temperature renewable resources can be utilised, such as heat pumps.

5.1 Role of District Heating

There are many advantages associated with a district heating system, which are summarised briefly here:

1. It improves the efficiency of the energy system by utilising surplus heat from power plants, industry, and waste incineration.
2. It enables additional renewable energy sources to be utilised which would otherwise be difficult to introduce into the energy system such as large-scale solar, large-scale heat pumps, geothermal heat, and surplus heat.
3. The level of comfort for the end-user is increased since there is no longer an individual boiler to maintain within the home (i.e. no fuel to order, no repairs, and no pollution issues), hot tap-water is

always available, and there is additional space available within the home (once the boiler is removed). These advantages often seem obvious in relation to the electricity network, since individual households no longer have individual electricity generators onsite. Even though district heating creates many of the same benefits, it is not currently utilised in many suitable locations.

4. It reduces the thermal capacity required compared to individual units since the thermal capacity is shared. Typically individual boilers are significantly oversized since they are designed to deal with the coldest day of the year. In contrast, the thermal capacity is shared in a district heating network so the overall investment in thermal capacity is much lower, which can result in significant cost savings.
5. It creates an additional source of flexibility on the energy system by introducing large-scale thermal storage along with large-scale heat pumps and electric boilers.
6. It increases the security of supply for the heating sector since the source of heat can be easily changed from one fuel to another. For example, if heat is delivered via the gas grid, then gas will always be necessary to provide the heat required. However, if a district heating system is constructed, then a boiler or CHP unit using any fuel could be used to create the heat required as well as surplus industrial heat, heat pumps, electric boilers, geothermal, solar, and waste incineration heat. Hence, the overall security of the supply is dramatically improved with the introduction of district heating.
7. Centralised systems can be maintained to a higher standard than individual boilers.

Some of the basic advantages associated with district heating can be can be quantified very easily by comparing a CHP plant to a combination of power plants and individual boilers. As outlined in Figure 30, a decentralised CHP plant can produce 52 TWh of electricity and 32 TWh of space heating using 100 TWh of fuel. In contrast, the combination of a centralised condensing power plant and individual boilers requires 120 TWh of fuel to meet the same demands. In a future with increasing fuel prices, this 20% additional fuel requirement plus the additional thermal capacity required for individual boilers, usually becomes more expensive than constructing a district heating network. In this study, the results from section 4 reflect this and hence the overall energy system is cheaper when district heating is introduced.

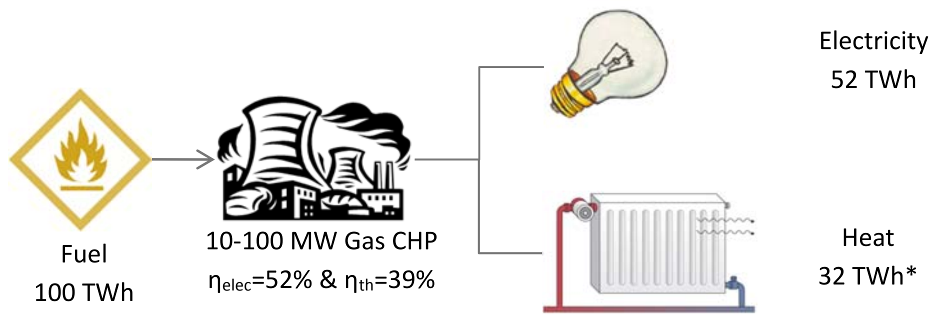

Figure 30: Energy flow diagram for a decentralised CHP plant to produce 52 TWh of electricity and 32 TWh of space heating. *Assumed a relatively high district heating network loss of 20%.

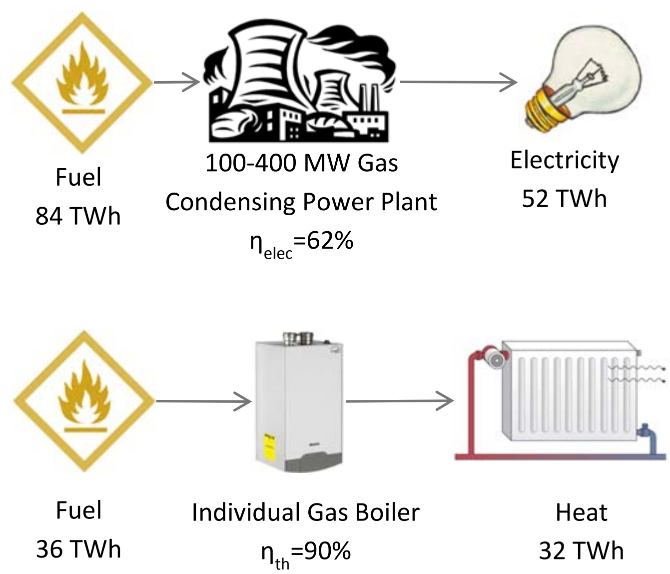

Figure 31: Energy flow diagram for a centralised condensing power plant to produce 52 TWh of electricity and individual gas boilers to produce 32 TWh of space heating.

5.2 District Heating in Ireland

To date, the most significant district heating network under construction in Ireland is in Dublin City [83], while a feasibility study has also been completed for Cork City [84]. However, this does not reflect the potential for district heating in Ireland. According to a comparison between Denmark and Ireland [85], the following key reasons were defined for the lack of district heating in Ireland:

- **No economic independence for local authorities:** the authors observed that County Councils can submit their projects, but it has to be approved by the ministry in Dublin, who control the finances.

As a result, the County Councils have very little financial independence so projects with local benefits can be difficult to implement.

- **Late arrival of electricity:** electricity only arrived in Ireland in late 1920's in urban areas, while rural areas did not receive electricity until after world war 2.
- **Location of power plants:** these are located far away from the urban population.
- **Historical poverty in Ireland:** in the past, Irish people often under-heated their houses to save money and so it was not feasible to introduce heating options with high initial investment costs, which is necessary for district heating.
- **National energy planning underutilised:** Ireland does not have an extensive tradition at developing national energy strategies or controlling energy using taxes. The authors noted that energy taxes are often used in Denmark to regulate energy consumption and production, whereas in Ireland taxes are predominantly a source of revenue.
- **Lack of local organisations:** There is a stronger tradition for creating co-ops or local environmental action groups in Denmark, which means that district heating has receive stronger support since it primarily benefits local citizens.
- **Industrial profile:** Ireland primarily consists of low energy industries due to a history of high energy prices and poor indigenous energy resources.
- **Low awareness of the benefits:** there is very little research outlining the benefits of district heating in Ireland: as a result, people are unaware of the benefits so nobody fights for district heating, which in turn means that there is not funding allocated to research the benefits.

The authors also suggested that the heat demand in Ireland is higher than in Denmark [85]: this suggests that district heating is a very suitable technology for the LCR. However, no quantitative analysis was carried out to confirm this, but instead this is based on observations of the building stock: for example, the average distance between the urban houses monitored in Ireland was approximately 4 m, whereas district heating regions in Denmark have houses up to 40 m apart. Since then, an EU report [86] has estimated the heat demand across Europe and the results indicate that the heat demand in Ireland is approximately 10% less than in Denmark (see Figure 32). As a result, it is very likely that Ireland has sufficient heat demands to warrant the development of district heating.

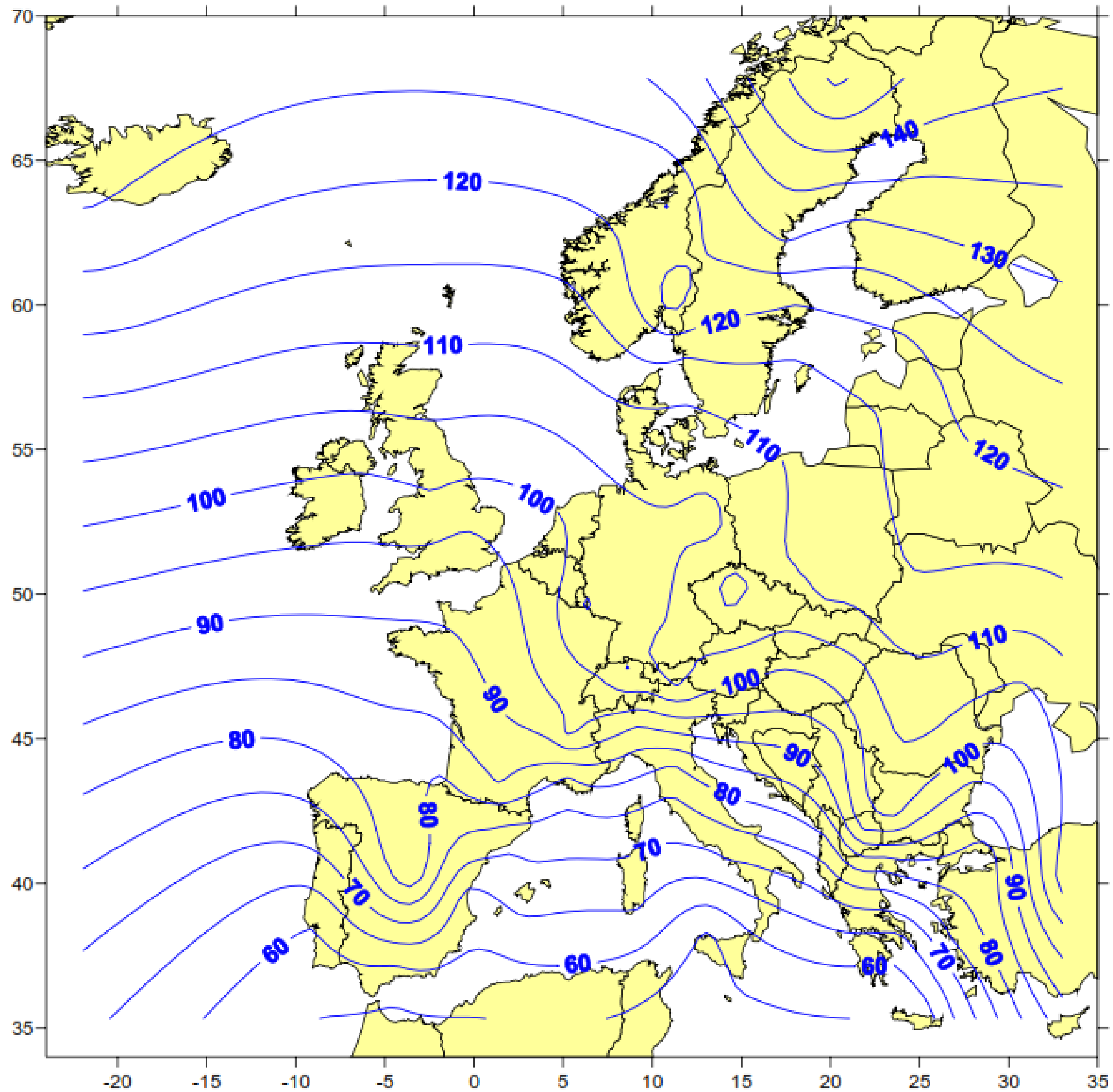

Figure 32: European space heating index across Europe (based on 80 locations) [86].

The level of surplus heat in the LCR also suggests that district heating is particularly suited for the LCR. As outlined in Figure 33, the ratio of surplus industrial heat in the LCR to the heat demand in the region is approximately 1-3 according to a recent EU study [87]. This was confirmed during the E&EB here while profiling the surplus heating from large energy users in the region [13]. Figure 33 also indicates that the LCR is one of the most abundant regions for surplus heat across Europe and hence, a district heating network could technically (although probably not economically) meet all of the heat demands in the region without using any fuel (i.e. just surplus heat).

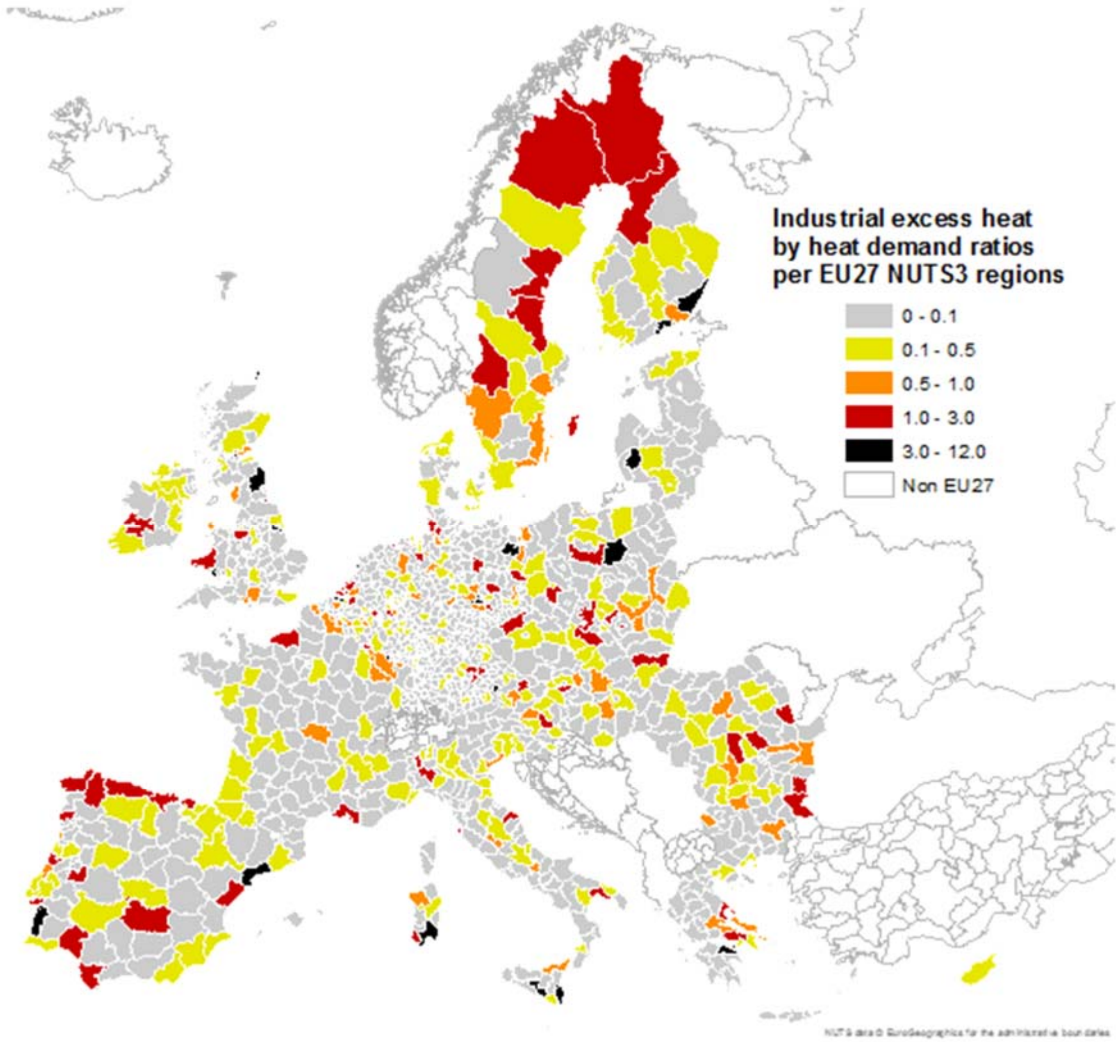

Figure 33: NUTS3 regions with respect to industrial excess heat by heat demand ratios [87].

5.3 District Heating Compared to the Gas Grid

Since the gas grid is already well established in the LCR, a gas grid for individual heating could still be considered for the future, even after outlining the benefits of district heating and how the biomass resource may never permit a 100% renewable gas situation (see section 4). However, for completion, a natural gas based system and a district heating scenario are compared in this section based on data for Limerick City. Note that this does not suggest that Limerick City is the only place to develop district heating, but it has been used since the data necessary was already subdivided in the E&EB report [13].

For this comparison the costs are calculated using a 3% interest rate along with the production unit costs and individual heating costs provided in Appendix II. Below are some key assumptions that should be clear when interpreting the results discussed here:

- The costs include a district heating network loss of 20%, so the total heat demand is 270 GWh.
- Since the heat produced for the district heating system is supplied using surplus heat already available in the system, the fuel required for this is not allocated to the district heating network. Instead of fuel, district heating networks require an investment in technologies to extract this surplus heat to the district heating network. For example, a CHP plant needs to be constructed to use surplus heat from electricity production or a heat exchanger needs to be constructed to extract surplus heat from an industrial process. However, even with this surplus heat, one additional fuel demand which is associated with the district heating network occurs in the boilers. Typically, these cover 5% of the annual heat demand since they operate while other units are in maintenance or to cover peak demands. Therefore, the only additional fuel directly allocated to district heating will be the fuel required for the centralised boilers.
- The district heating network has been modelled in the EnergyPLAN tool to identify the capacities necessary to meet the heat demand. The total production capacities are 40 MW CHP, 100 MW boilers, and 6 GWh of thermal storage. It is assumed that the CHP and boilers both use natural gas.
- Even though the boilers only operate approximately 5% of the time, there are enough boilers installed to cover the annual peak demand, which is common practice to ensure there is never a shortage in the heat supply.
- Individual natural gas boilers have a 97% efficiency, so the total demand for gas is 245 GWh.
- There is already a gas network constructed in Limerick City. Hence, there is a certain proportion of annual operating costs associated with the network (€3.15/GJ [7]), while the rest are considered 'sunk costs' (€4.3/GJ [7]). These 'sunk costs' cannot be recovered unless all users stop using the gas grid, so if only some of the individual consumers stop using the gas grid then the rest have to pay for these costs [7]. The proportion of the total gas grid costs which can be considered as sunk costs is highly debatable and hence so is the validity of including/excluding them in a socio-economic analysis for the year 2020: on the one hand, they should be included since these are investments that consumers need to pay to keep using the gas grid, but on the other hand they should be excluded since the gas grid is already built and will continue to be used by some customers by 2020. To be conservative in this comparison, these sunk costs have been excluded in 2020. However in 2050, these sunk costs will be part of the natural gas grid costs, since by then the technical lifetime of the gas grid will be exceeded and so the gas grid will need to be refurbished at some point between now and then.

Looking at the results, Figure 34 indicates that using natural gas to heat the buildings in Limerick City will cost the same as a district heating network in 2020, based on the assumptions outlined previously. However, the composition of the costs is very different: for the natural gas grid, fuel is the primary cost whereas for the district heating network investment in technologies is the primary cost.

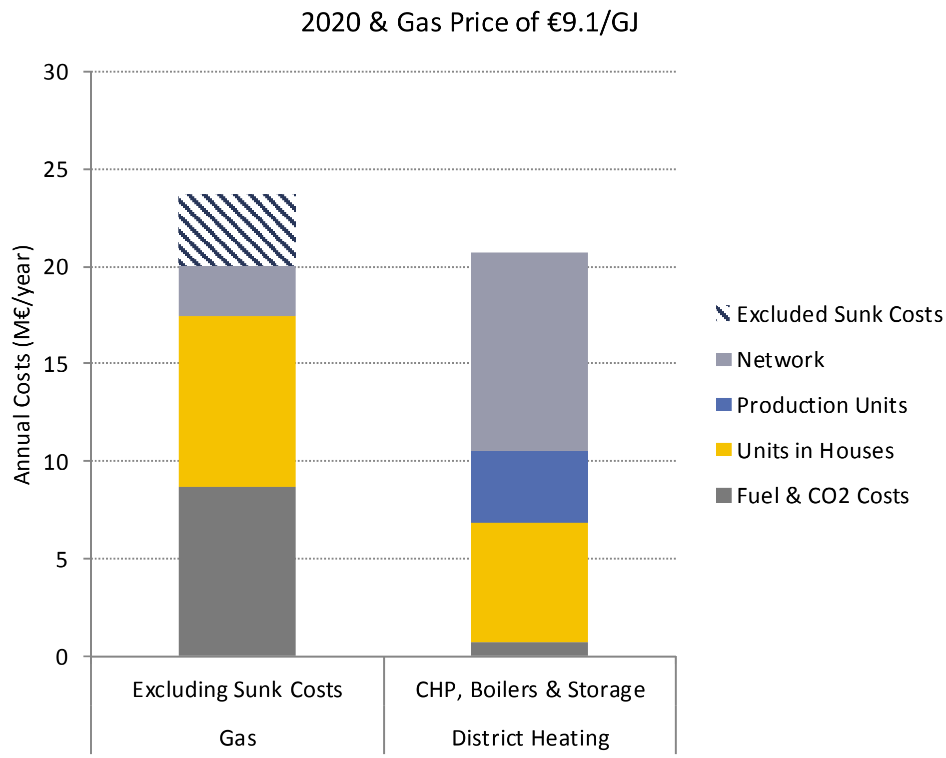

Figure 34: Cost comparison between the use of natural gas and district heating to supply the heat demand in Limerick City based on 2020 fuel prices and investment costs: since the natural gas grid is already constructed in Limerick City, the sunk costs are excluded.

Forecasting these costs to 2050, Figure 35 indicates that the cost of the natural gas grid will increase significantly in comparison to the district heating network: overall natural gas becomes approximately 30% more expensive. The primary reason for this is the trend in fuel prices: since natural gas is primarily fuel-based while district heating is investment-based, the forecasted increases in natural gas prices in 2020 and 2050 cause the cost of natural gas heating to increase significantly. In contrast since the district heating network is based on investments, it is not as sensitive to these future increases. Although it is not presented in Figure 35, a sensitivity analysis was carried out where the natural gas 'sunk costs' were removed from the 2050 scenario also. Even in this case, the natural gas grid is still 10% more expensive than the district heating network. In conclusion, district heating is not only competitive with natural gas based heating in the short term (2020), but from a long-term perspective (2050), it is a cheaper alternative.

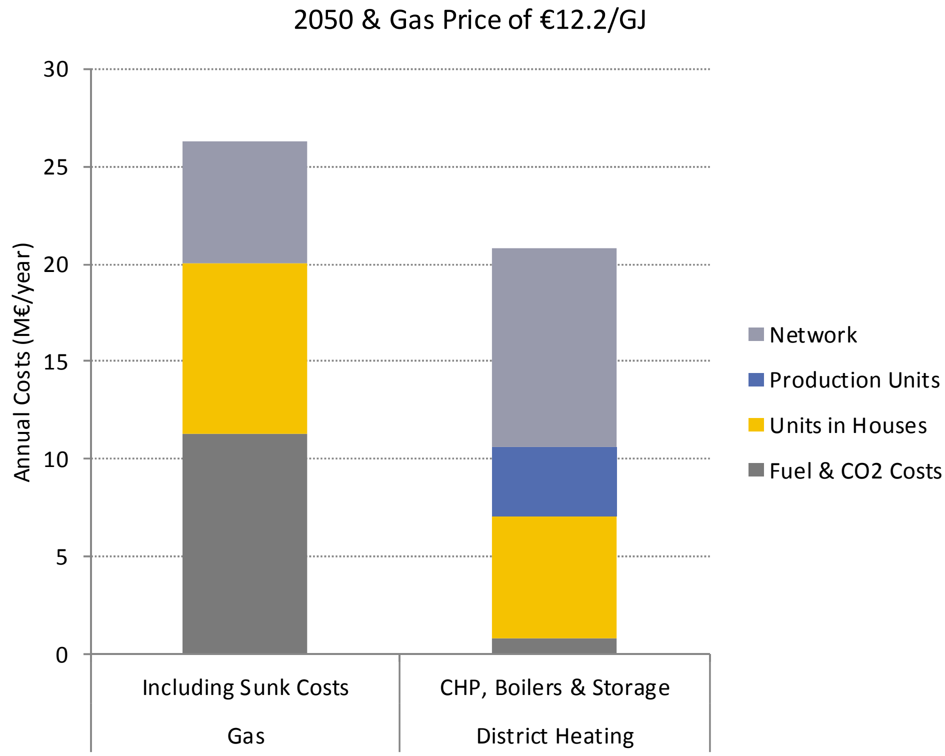

Figure 35: Cost comparison between the use of natural gas and district heating to supply the heat demand in Limerick City based on 2050 fuel prices and 2020 investment costs: since the natural gas grid in Limerick City will come to the end of its technical life before 2050, the sunk costs are included.

It is worth noting that district heating also competed with natural gas in Denmark at the early stages of development, but district heating began to dominate since it was also a cheaper solution at that time. In addition, district heating in Denmark received very few grants during its development: the only major subsidy was low-interest loans for co-ops and local authorities [85].

6 Playing a role in a national 100% renewable energy system

Although this study has focused specifically on the actions that can be taken by within the LCR for the LCR, it is important to recognise that the region will probably have to take additional actions if a national 100% renewable energy system is to be achieved. This is briefly highlighted here by outlining how the region could export additional renewable energy and the importance of sharing the biomass resource.

6.1 Exporting Intermittent Renewables

It is clear from the renewable energy resources that the LCR has more than enough intermittent renewable energy resources than required in the region (see Figure 18 and Appendix VIII). If Ireland is to reach 100% renewable energy, it is likely that the urban areas of Ireland (particularly the greater Dublin area) will not have a surplus of renewable energy and so it will need to be obtained in other parts of Ireland. Since there is already an excellent electricity network infrastructure between the LCR and Dublin, this offers a unique opportunity for the region to export its intermittent renewable energy.

To investigate this, a very brief analysis has been carried out: instead of simulating a closed energy system for the *LCR 2020* scenario, an 'open' system is modelled. In other words, the transmission capacity out of the region is added to the model so it can be used to export renewable energy in the analysis. As a proxy, it is assumed that the minimum capacity available on the 400 kV lines between the LCR and Dublin can be used to export power: this is ~1425 MW according to EirGrid [88]. Since the power plant capacity required for the LCR is approximately 400 MW, which leaves approximately 1000 MW available for exporting intermittent renewable energy only, so this is the assumed export capacity available. By using this transmission capacity to export electricity, it is possible to build more wind power in the LCR while still ensure the grid is operated reliably. Therefore, the wind capacity was increased in the 'open' *LCR 2020* scenario until the same amount of wind power was curtailed as in the 'closed' system. The results indicated that wind power could almost be tripled in the region (from approximately 350 MW to approximately 1100 MW) without exceeding the export capacity available, while still operating within the restrictions EirGrid have set for the maximum instantaneous penetration of wind on the grid (which is approximately 70% [29]). This simply highlights the potential scope for additional actions within the region to contribute towards a 100% national renewable energy system, but concrete actions would require a more detailed analysis.

6.2 Sharing the Biomass Resource

Earlier in this report, the long-term concerns relating to biomass consumption were highlighted (section 4.1) as well as the large consumption necessary in a 100% renewable energy system (section 4.3). However, all of the scenarios investigated for 2020 and 2050 in this study assumed that the Large Energy User's (LEUs) consumption was equally shared across Ireland, due to the scale of their consumption (this has been discussed in detail in the E&EB [13]). This effectively means that there is an underlying assumption that in a 100% renewable energy system, the biomass resource would also be shared across Ireland, where regions like the LCR which have a particularly high industrial demand could rely on biomass from other regions which have a lower energy consumption.

For completeness, a scenario has been considered here where the LCR is responsible for all of the energy consumed by the LEUs in the region. In this scenario, then the biomass demand in the *LCR 2050* scenario would increase from ~2.7 TWh up to 7-9 TWh, depending on how these industries grow/save energy in the future. This increase of ~5 TWh would mean that the biomass demand in the *LCR 2050* scenario would now be ~12 TWh, while the total potential resource in the region is 13 TWh. This highlights the importance of a shared biomass resource across Ireland in a 100% renewable energy system and once again demonstrates a potential biomass bottleneck unless strategic alternatives are identified. For example, the industrial demand for biomass could be significantly reduced by converting biomass boilers to electricity, which could subsequently use the abundant intermittent renewable resource in the region.

7 Implementation and the Role of Local Authorities

This study has primarily focused on the technical design of a sustainable energy system for the LCR. After defining a pathway, the next key challenge is implementing those actions. It is not possible to identify the exact steps necessary within this study, as previous research has outlined the variety of potential options [89]. Instead, this section will highlight the key role that the local authorities in the LCR can play while overcoming the barriers with local renewable energy projects [90].

As the energy system moves from a fuel based system to an investment based system (see section 4), the role of energy organisations will also change dramatically [91]. For example, the existing energy system requires large organisations which can buy and transport fuels to the power plants as well as organize the construction and operation of these plants. However, when dealing with renewable energy such as wind power, there is no fuel transportation and the wind turbine factories build the wind turbines. Therefore, the existing organisation will need to adapt or else new organisations will be formed. Since this transition also means that local resources instead of imported resources are used for energy production, local authorities will play a key role in the transition to a sustainable energy system.

In line with this, the purpose of this chapter is to discuss the importance of energy planning at the local level and to outline the basic elements of local energy planning as a (new) domain of public planning in the context of 100% renewable energy systems (100% RES). It is argued that local energy planning is crucial for the successful implementation of national renewable energy strategies, and that such planning will have to evolve in response to the complex and comprehensive changes that need to happen in order to create 100% RES. Local authorities are identified as “ideal” local energy planning authorities in this regard, based on a brief outline of some main building blocks and requirements in (integrated) local energy planning.

7.1 Sustainable energy systems and the need for energy planning at the local level

An increasing number of countries and regions are beginning to implement energy strategies, which aim at developing energy systems that are independent of fossil fuels. An important element of these energy system transitions will be an increasing decentralisation of energy systems. In short, this means that systems based on a few large, central (electricity) production units will be transformed into systems based on many small, distributed production units. Some of the main drivers for this decentralisation include the need to replace (imported) fossil fuels with local renewable energy sources. The availability of these resources, including wind power, solar energy, biomass, hydro power, ocean power and geothermal energy, can vary considerably within one country and one year or even a day. Therefore, these resources have to be utilised where and when available, resulting in a (potentially) large number of energy installations locally.

In order to reduce and replace the consumption of fossil fuels, the overall fuel efficiency of the energy system has to be increased, not least due to the limited availability of most biomass resources. This means that, both, the energy demand has to be reduced and energy has to be produced and consumed more efficiently. Moreover, energy will have to be consumed more intelligently due to the intermittent availability of many renewable energy resources, which requires e.g. a better integration and communication between supply and demand as well as shifting energy production and consumption between sectors in the energy system. Thus, future energy systems will be increasingly supply driven, as opposed to demand driven fossil fuel based energy systems (see Figure 36).

Examples of efficient energy technologies include district heating and CHP. Establishing district heating systems (based on e.g. CHP units) requires detailed local heat planning, examples of which have been carried out in Denmark and Sweden from the 1980's and onwards. Having a district heating system can allow for the use of industrial excess heat. The use of heat pumps is not only an efficient way to produce heat using electricity, but it also offers the possibility to utilise part of the excess electricity from intermittent wind and solar power production, for instance. Apart from that, large heat pumps can be integrated into a district heating system. Intelligent charging of electric vehicles, flexible electricity consumption in households and industry as well as energy storage options, such as pumped hydro and hydrogen produced by means of electrolysis, offer other good possibilities for the integration of intermittent renewable energy into the energy system and a better integration of the heat, transport and electricity sectors. Solar thermal collectors in conjunction with (seasonal) storages are other local renewable energy options that are finding their way into individual and district heating systems.

With regard to energy demand reduction, households' energy consumption is a main focus area. The reduction of buildings' energy demand is a major prerequisite for achieving efficient energy systems. As a number of studies based on the Danish system have shown, this reduction of the energy demand has to be integrated with the planning of heat supply options, both, in individual buildings and district heating networks [67, 68]. When it comes to biomass, resources are limited and often unevenly distributed between rural areas with relatively low energy demands as well as higher shares of renewable energy resources and urban areas with high energy demands and fewer renewable resources. Therefore, (biomass) resources need to be mapped at the local level in order to gain a comprehensive picture of their availability.

Altogether, the above options are mostly *local* solutions that have to be implemented either at the community level (e.g. district heating, wind power) or at the level of individual households (e.g. energy demand reduction, flexible energy consumption). Their implementation will be a crucial part of achieving national energy goals and they require a detailed and integrated planning at the local level. This means that the national 100% RES will first and foremost take shape at the local level, and can therefore be considered as energy systems that are composed of many, integrated local sub-systems. It will be difficult to plan and implement these local sub-systems at the central level, since much of the knowledge and competences required can be found at the local levels. However, the planning and implementation of local energy systems requires support from the central level. This is elaborated in the sections below.

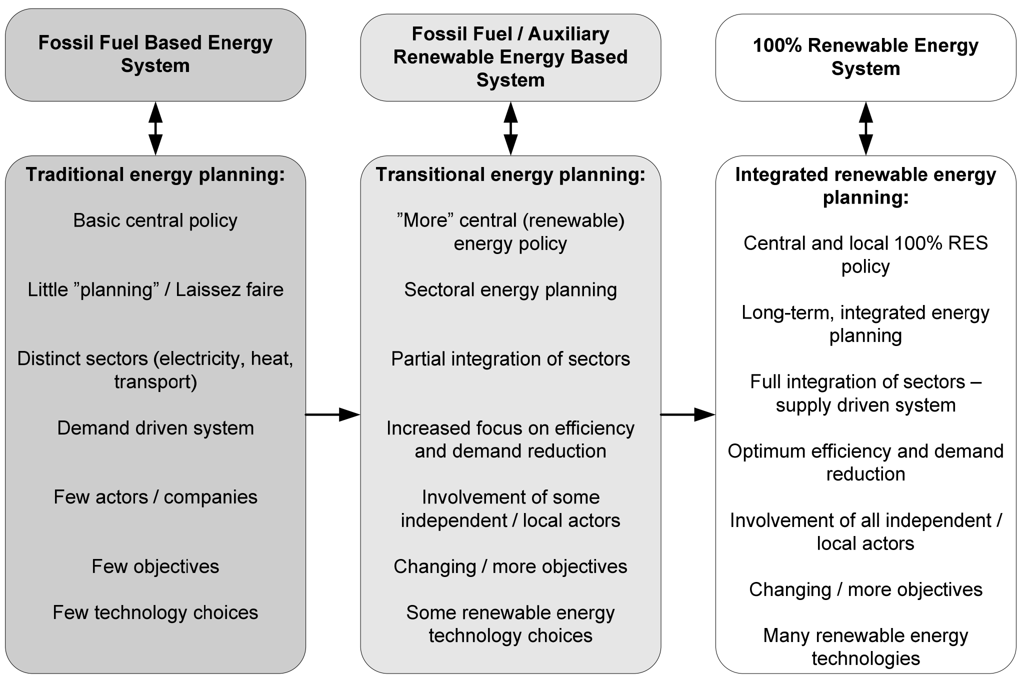

Figure 36: The evolution of energy systems and energy planning as reciprocal processes [92].

7.2 What is integrated local energy planning?

Local energy planning as a task of local and regional authorities has been developing throughout the last 35 years. Especially in some Scandinavian countries local energy planning has been outlined by means of more or less comprehensive legislation. In Sweden, the municipal energy planning act has since 1977 been a guideline for local authorities, initially aimed at reducing the dependence on oil in the local authorities and later on incorporating broader goals, such as climate change mitigation [93, 94]. In Denmark, effective heat planning in the local authorities, which was coordinated by the counties during the 1980s and 1990s, has led to a drastic reduction of oil consumption in the heat sector. Among others, this was achieved by the introduction and clear division of heat supply areas based on either district heating or individual natural gas supply [95]. Thus, municipal heat planning in Denmark also was a crucial prerequisite for the development of the many decentralised CHP units and the establishment of a comparably efficient heat sector. However, municipal heat planning has since been dormant in Denmark and the local authorities have mostly concentrated on maintaining the existing heat supply areas. This will have to change, considering the need to phase out natural gas and expand district heating in the near future.

What has characterised local energy planning in most countries until recently is the focus on individual components of the energy system. In Sweden, municipal energy planning was in the past mainly driven by local energy companies with a strong focus on the heat supply side. In Denmark, this was accompanied by a strong local wind power movement, which necessitated the establishment of municipal wind power planning. Global initiatives, such as Local Agenda 21, and a changing focus in national energy policies with regard to climate change and supply security, have had an influence on the scope of local energy planning over time. While it can be argued that local energy planning to a certain extent follows national policy goals, local authorities also tend to emphasize those areas in which they possess some ability to act [25]. This means that local energy planning on the one hand has become more comprehensive, including more sectors and components of the energy system as well as taking more policy goals into account. On the other hand, especially municipal energy planning still seems to remain most effective within those fields where local authorities and local energy companies have executive powers; i.e. leading to the implementation of concrete projects. Other areas in which responsibilities are unclear or are with actors other than the local authorities and local energy companies, are less concretely defined and may not lead to the implementation of concrete projects.

In the light of 100% RES, local energy planning will have to be turned into a tool that effectively takes into account all aspects of future energy systems. The notion of a more "comprehensive", "integrated" or "advanced" local energy planning is more than 10 years old. In their guidebook, Steidle *et al.* ([3], p. 12) define Advanced Local Energy Planning as a "*combination of the use of energy models for comprehensive and detailed energy planning, participative involvement of affected groups and modern methods of project management"*. It implies that the various components and sectors of energy systems, i.e. within heat, electricity, transport, have to be understood and analysed in an integrated way already at the local level. Having reached such an integrated picture of (local) energy systems will make it possible to develop concrete and efficient action plans within the various sectors of the energy system, minimising the risk of sub-optimisation and (undesirable) technological lock-ins.

Steidle *et al.* [3] describe the types of "sub-system energy planning" that, for instance, characterised much of (local) energy planning in the past as the "traditional approach" to energy planning. There are several reasons for why instead of the traditional approach a more integrated approach to local energy planning should be taken (adapted from [3], pp. 15-16):

- Separate analysis and optimisation of sub-systems is insufficient as it does not take interdependencies between system components into account; i.e. between heat, electricity and transport sectors and their various sub-sectors. Changes to one sub-system may affect other sub-systems.
- Energy systems can consist of long-lived infrastructures (e.g. district heating networks, power plants, distribution grids) that either enable or inhibit changes in other sub-systems. Long-term planning is important to evaluate the effects of these infrastructures in light of 100% RES.
- Supply-side measures can compete with demand-side measures (e.g. energy production units may depend on a certain level of consumption in order to run economically).
- The feasibility of long-term investments depends on somewhat uncertain socio-economic factors, such as energy prices, (environmental) taxes and technological development, which need to be taken into account in the comprehensive analysis.
- Different actors and local interest groups with potentially opposing views and goals have an influence on different components of the local energy system. All of these groups should be involved in the planning process.
- Energy planning is related to other fields of planning, including environmental planning, urban planning and transportation planning, which requires energy planning to be coordinated and integrated within local planning in general.

On this basis, main components of an integrated local energy planning can be outlined. Here, the following five principles are suggested and elaborated briefly.

1. Long-term perspective based on 100% RES

Integrated local energy planning is understood as energy planning that provides for the implementation of 100% RES at the local level. A timeframe of 30-40 years will typically have to be taken in order to make such a transformation conceivable. One main reason for this is the above-mentioned long-term character of some energy infrastructures, which on the one hand require long-term investment frameworks to increase their feasibility. On the other hand, longer time horizons can facilitate envisaging solutions that are not inhibited by current energy system infrastructures. This "inertia" of the energy system is, at the same time, a good reason for working with a 100% RES target, instead of only defining intermediate targets as end points. It should be made sure that investments made in the short and medium term do not defer or hinder the achievement of the 100% RES goal in the long term. Another general reason is the state-of-the-art and costs of certain renewable energy solutions, which are likely to be improved in the future. Thus, in integrated local energy planning concrete and quantitative targets are developed, based on long-term visions of local 100% RES. Integrated local energy planning is furthermore a means to translate these visions and targets into tangible and feasible projects (in the short term).

2. Integrated analyses of the energy system

Integrated local energy planning develops and analyses concrete 100% RES scenarios of the local energy system, taking into account all sectors (electricity, heat, transport) and their interdependencies. This will in many cases necessitate the use of energy system analysis tools as well as other software tools that can simulate and quantify the complexities involved in simultaneously changing and optimising the various sub-systems in the energy system. Such integrated analyses should take point of departure in a detailed description of the existing energy system and a quantification of the local (long-term) potentials for renewable energy exploitation, efficiency improvements and energy demand reduction. In adopting such an integrated supply-demand perspective local energy planning should furthermore include socio-economic analyses in order to assess the feasibility of investments in the different energy system scenarios. This will be important in relation to assessing the effects of the energy system transformation on the local economy. Furthermore, socio-economic assessments are necessary for the identification of (market) barriers that may make otherwise optimal solutions seem infeasible in current energy systems. By taking into account existing key technologies that are likely to facilitate the transition to 100% RES the definition of concrete local projects may be supported. At the same time, integrated energy system analyses need to be responsive to developments at the national system level and in other local authorities in order to ensure that the local energy system can be a part of the national 100% RES transformation. For instance, a local authority should not exceed its “biomass quota” in relation to the nationally available resources. Finally, integrated local energy planning should take into account the effects of the energy system transformation on other sectors outside the energy system, and vice versa. Again, the use of biomass can be an example, which can lead to changes in the agricultural sector.

3. Internal coordination of the energy planning process

Integrated local energy planning will in most cases have to be developed as a field of (local) planning. Performing integrated analyses of the energy system and developing long-term scenarios requires competences that still need to be acquired in most local communities. It needs to be ensured that there is coherence between energy planning and other local planning tasks and that local energy planning becomes an integral part of the strategic development plans of local communities. It is important that local energy planning becomes a continuous planning process with clearly defined responsibilities among the various local planning departments. Strategic long-term planning is a task that involves considerable complexity and uncertainty, which can for instances be handled by establishing internal learning processes based on a continuous revision of the local energy plan. In that sense, integrated local energy planning can be seen as working towards a common vision in a flexible way.

4. External coordination of the energy planning process

Effective local energy planning needs the support of the local community and depends on the close cooperation between local and other actors. A well-known guideline from public planning is that those groups that are affected by planning decisions should be involved in the planning process. Building networks and working groups of relevant (external) actors can be a way of rooting the energy planning process in the local authorities, thereby increasing the chances for having concrete projects realised. Most of the solutions in a 100% RES will require the cooperation between local authorities and external actors. Examples include utility companies, which are main actors with regard to local electricity distribution grids and collective heat supply solutions, such as district heating. Residents need to be involved systematically, since substantial energy demand reductions and renewable energy solutions, such as solar power and heat, require relatively large investments and/or interventions in existing buildings in combination with a more conscious consumption of energy. Transport organisations can play a crucial role in relation to expanding public transport solutions and establishing the necessary infrastructure for alternative propulsion systems, such as electric vehicles. Agricultural organisations can be relevant partners when planning to assess and use local biomass and biogas potentials. Local authorities play a key role in building up dialogue and cooperation with all of these actors – not least due to the fact that they often already are involved in the planning of most local infrastructure changes. In Denmark, for instance, local authorities are the main public planning authorities in relation to large wind power and biogas installations.

Apart from building effective local and regional networks, local energy planning authorities should also provide input to national energy policy making. Such input is necessary to ensure the implementation of new solutions at the local level. This point is elaborated further in section 7.3. Finally, a good coordination of local energy planning with similar initiatives at the county/regional level is important to avoid sub-optimisation and inefficient resource use between neighbouring local authorities. As an example it might be more convenient to share biomass resources between local authorities instead of focussing exclusively on one local authority.

5. Local ownership and involvement

As stated above, integrated local energy planning should be borne by a range of local actors and communities. Local public acceptance and involvement are strongly linked with each other, and creating local investments in renewable energy and energy conservation will in many cases lead to greater support for local energy planning among local communities. Community ownership is one way to distribute investments and the associated benefits among a (relatively wide) group of local actors. Danish wind power and CHP development has in the past been characterised by a strong movement of local cooperative ownership schemes, and consequently, by a very low public resistance against wind turbines and district heating. Local authorities can be key actors in this regard, as they not only have planning responsibilities, but can also invest in and own renewable energy solutions. Many of the local utility companies that operate CHP plants and district heating networks in Denmark, for instance, are owned by local authorities. Moreover, a focus on local investments and ownership can not only be beneficial for improving local cash flows, it can also contribute to local job creation. Substantial energy-efficient retrofitting of buildings is an example that can lead to a potentially significant creation of jobs among the local building trade. Apart from that, by taking action in relation to public buildings and other infrastructure local authorities can set a positive example and demonstrate renewable energy solutions at the local level.

7.3 The relation between integrated local energy planning and central energy planning

The above sections underline the crucial role of local authorities in integrated energy planning. Local authorities represent and can influence the interests of local communities; they are the main coordinators between actors in the local network; they already have the responsibility for other fields of strategic planning; and they constitute the link between central policy making and local communities, and as such translate national goals into local action. In short, local authorities possess or can access the necessary types of expertise required in integrated local energy planning. Through their roles as planning authorities, initiators, facilitators, investors and owners with regard to renewable energy solutions they can be the main drivers in (local) 100% RES planning.

Integrated renewable energy planning is a planning field that will have to be developed and implemented at, both, the central and local levels. While local authorities are seen as the main drivers of integrated local energy planning, central authorities will have to ensure that such planning actually is possible and effective (see also [25, 96]). As sketched in Figure 37, one main central task is to establish a clear, long-term energy policy that is ideally based on the vision of a national 100% RES. Such a clear central policy will serve as a guideline for integrated local energy planning and will ensure coherence between the various energy planning activities at the local level. In Denmark, not all responsibilities in terms 100% RES planning have been distributed between the central and local levels of planning as well as other actors, yet. This has, among others, led to a situation with many local authority energy and climate plans that greatly differ in scope, detail and ambition [25]. Such a situation increases the risk of creating sub-optimisations in the national energy system. It can also lead to a slowing down of the planning activities in ambitious and proactive local authorities, since it remains unclear which technical and non-technical solutions can actually be supported by the central level.

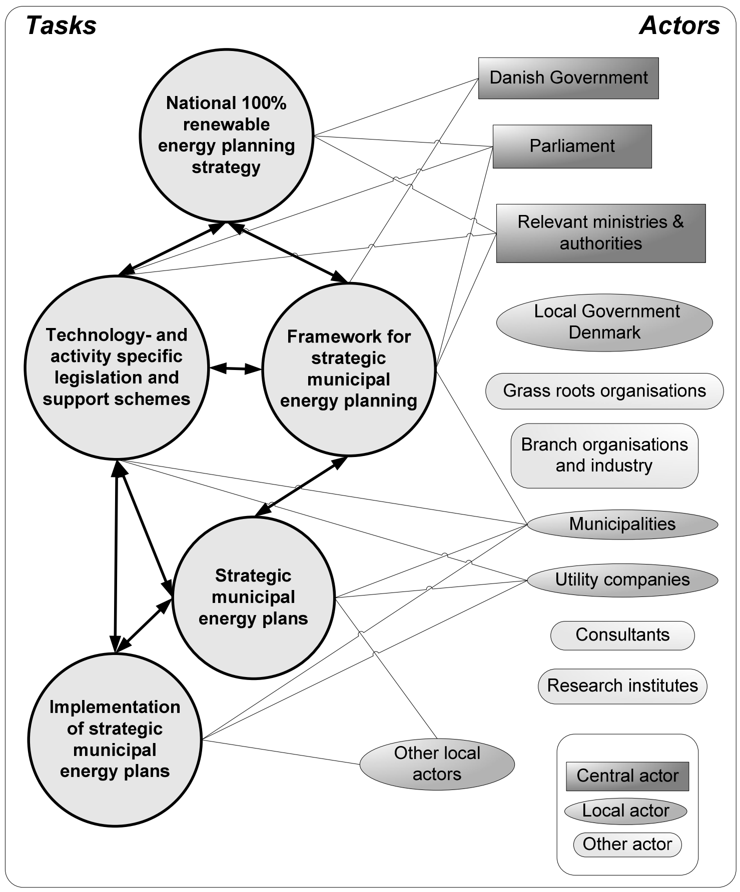

Figure 37: Outline of main components in an Integrated Renewable Energy Planning System [25].

Integrated renewable energy planning as an umbrella term for energy planning at the central and local levels, thus should be a continuous process that is based on an open and intensified dialogue between the state, the local authorities with the input and participation of industrial organisations, NGOs and research institutes (see Figure 37). Besides setting up a clear framework for integrated local/municipal energy planning based on a long-term energy policy, the state also needs to provide clear support and legislation so that local energy plans actually can be implemented through concrete projects. In Figure 37, this is termed “technology- and activity specific legislation and support schemes" and could, for instance, consist of direct support in the form of feed-in tariffs or a reform of energy-related taxation. In other cases it might turn out to be more effective for the state to empower local authorities and other organisations to design their own solution-specific support schemes. Again, one essential point here is that since actors at the local level are the main implementers of integrated energy solutions, they should also be involved in the design of these solution-specific support schemes. Hence, there should be room for the local level to participate in the design of energy-related legislation, not least because experimenting and learning with new energy solutions will happen at the local level. Local energy planning can in that sense also be an important instrument to demonstrate new energy solutions that may be eligible to receive stronger support (by central government).

Denmark is a good example for which challenges can arise during the establishment of an integrated renewable energy planning system. Planning and implementing 100% RES is a complex process that involves many uncertain factors. Consequently, central and local authorities might feel unprepared for or overwhelmed by the task. Not having clear frameworks and guidelines can lead to situations in which local authorities either feel unable to initiate effective energy planning processes or where a large variety of differing and potentially opposing local energy plans is developed, as the Danish example illustrates [25]. This underlines the importance of integrated (local) energy planning: by following the five principles of integrated local energy planning, local authorities can approach energy planning more holistically, which seems likely to lead to similar solutions in local authorities in general. The main reason for this is that in applying integrated local energy planning, local authorities will be more inclined to focus on efficient solutions that create positive synergies within the energy system and that are beneficial to the local economy. As a consequence, following similar guiding principles in local energy planning seems likely to lead to similar solutions in different local communities. The assumption is that the principles of integrated local energy planning can contribute to reducing large fluctuations in the content and scope of local energy plans and thus the risk for sub-optimisations.

After having discussed some main principles of integrated local energy planning as well as the important role of local authorities, one question that might remain is how the activities that are suggested in the integrated local energy plan should be prioritised. Since such a plan may take point of departure in a future 100% RES vision that lays 30 or 40 years ahead, it seems natural that some of the planned activities cannot implemented immediately in the local communities yet. The integrated local energy plan can be a tool to structure these activities into short-, medium- and long-term projects. In the short- and medium term, priority should be given to activities that increase the efficiency of the energy system, including conservation and demand reduction measures. Short- and medium term activities should be "transition solutions" that link the existing energy system with a 100% RES – in other words, solutions that under all circumstances will play a role in the future energy system (e.g. heat demand reduction in combination with expansion of district heating). As described in the above sections, local authorities will have to make use of their networks as well as expand these networks during this process. It is in this regard also crucial that local authorities play an active role in establishing a close dialogue with the central levels of planning. This is especially relevant regarding the long-term solutions for which existing support schemes are weak or even absent. Since there in most cases is an equally strong need for capacity building at the central level in terms of energy planning, local authorities can provide valuable input regarding (legal) barriers and inadequate support schemes. Presenting local 100% RES plans to the central level and initiating a corresponding public dialogue will therefore be a relevant input to national energy policy making. Finally, through the participation in transnational networks of local authorities, for instance, local authorities will gain access to solutions and best-practice examples from communities abroad [96]. Integrated renewable energy planning will thus have to be associated with a stronger political activity at the local levels of planning in order to create a better alignment between national/international targets and policies and the concrete actions of local actors.

8 Conclusions and Recommendations

A future sustainable energy system will look very different to the existing energy system in the LCR. From a technical perspective it will require the integration of the electricity, heat, and transport sectors, while from an economic perspective it will be an investment-based system instead of a fuel-based system.

The analysis in this study has identified different energy alternatives that could be followed in the LCR in 2020 and 2050. Based on the results, the authors recommend that existing national policies outlined under the NEEAP and NREAP in relation to energy efficiency and intermittent renewable energy production are followed in the region to 2020. However, an alternative approach should be considered in the heating sector: district heating should be implemented in the urban households where the heat demand is sufficient while heat pumps should be implemented in rural households outside of district heating areas. This will result in a more efficient energy system and create approximately 2,000 more local jobs. Also, specific focus should be placed on biogas production from waste resources in the region, which could subsequently be used in the CHP plants constructed. Other biomass resources from waste or industrial by-products should also be utilised where possible. In relation to transport, electric vehicles should be implemented in line with national targets, but biodiesel and bioethanol need to be evaluated from a long-term perspective. In other words, where biomass resources that require land-use change are implemented, it is vital to ensure that it contributes to a long-term sustainable strategy. Due to uncertainties in relation to these resources and conversion processes, the authors have assumed that national targets will be followed, but recommend that these are further debated and discussed to ensure they are in line with a sustainable solution.

Table 8: Key capacities and demands for the national *NEEAP/NREAP* scenario and the alternative recommended scenario (*LCR 2020*) for the LCR in 2020.

Sector	Input	2020 Scenarios	
		NEEAP/NREAP	LCR 2020 (DH&HP+RE)
Power Plants and District Heating	Condensing PP (MW)	479	478
	DH Demand (TWh)	0	0.198
	CHP (MW)	0	65
	Thermal Storage (GWh)	0	5.21
	Heat Pump (MW)	0	5
	Boiler (MW)	0	89
	Solar (TWh)	0	0.018
	Solar Storage (GWh)	0	0.390
Intermittent Renewable Electricity Sources	Wind (MW)	330	330
	Hydro (MW)	86	86
	PV (MW)	0	25
	Wave (MW)	0	0
	Tidal (MW)	0	10
Individual Heating	Coal Input (TWh)	0.155	0.109
	Oil Input (TWh)	0.973	0.682
	Natural Gas Input (TWh)	0.691	0.484
	Biomass Input (TWh)	0.134	0.134
	Heat Pump Heat Demand (TWh)	0.023	0.250
	Electric Heating Heat Demand (TWh)	0.268	0.201
	Solar Heat Production (TWh)	0.007	0.094
Electric Vehicles	Electricity Smart Charge (TWh)	0.031	0.031
	Grid to Battery Connection (MW)	76	76
	Battery Storage Capacity (GWh)	0.38	0.38
	Number of EVs	15,000	15,000
Biofuels	Biogas (TWh)	0	0.459
	Biodiesel (TWh)	0.226	0.226
	Bioethanol (TWh)	0.097	0.097

Crucially, this study has also outlined how the actions in the recommended *LCR 2020* scenario will fit with the long-term objective of 100% renewable energy in the LCR by 2050. After assessing nine different 100% renewable energy systems in 2050 for the LCR, the results indicate that a combination of intermittent renewable energy, biomass, biogas, district heating in the urban areas, heat pumps in the rural areas, electrolysers, and electric vehicles will provide the cheapest 100% renewable energy system in 2050. Hence, the actions outlined for 2020 will contribute to this end goal. In addition, due to rising fossil fuel prices and decreasing renewable energy investment costs, it is likely that this alternative will be a cheaper alternative than a fossil fuel based system for the region: this could not be verified since 2050 investment costs were not collected during this study. Furthermore, there are additional benefits for the region such as increased local job creation (approximately 8000 more), less pollution, more stable long-term energy prices, a new brand as renewable energy region, and a better balance of payment for the region (instead of a net loss of approximately M€300/year on importing fuel, the LCR will have a net gain of €200/year due to local investments).

8.1 Key Conclusions

- **More renewable energy is possible in the LCR by 2020, while also reducing energy costs and creating 2,000 more local jobs.**
  By 2020, the LCR can produce 70% of its electricity and 25% of its total energy demands from renewable energy if the 'LCR 2020' scenario in this study is implemented. Furthermore, this can be done while also reducing the cost of energy, reducing greenhouse gas emissions, reducing the demand for energy, and also creating approximately 2,000 local jobs within the region.

- **Particular focus should be placed on the heating sector in the LCR between now and 2020.**
  There are well-established technologies which can be implemented immediately in the LCR. The primary solutions that should be implemented are district heating in the urban areas and individual heat pumps in the rural areas. For the electricity and transport sectors, actions outlined by the Irish government should be implemented.

- **District heating is a cheaper alternative than natural gas for individual urban buildings.**
  District heating is explicitly discussed in this report since it is not a well-established technology in Ireland. As part of this discussion, district heating is compared to natural gas since the gas network is already well-established in the region. The results verify that district heating is a cheaper alternative which will also generate more jobs for the local economy (since it is an investment-based solution unlike natural gas which is a fuel-based solution).

- **A 100% renewable energy system will offer significant benefits for the local citizens of the LCR.**

This includes approximately more local jobs, less pollution, new skills and new business opportunities. Results indicate that if the LCR achieves a 100% renewable energy system by 2050, it will be cheaper than a fossil fuel alternative if fuel prices continue as forecasted. The impact of the balance of payment for the region is also positive, going from a net loss based on importing fuel to a net gain based on local investments. Therefore, renewable energy should not be viewed as something that the region needs to do, but instead as something that can be done to improve local society.

- **It is important to ensure that the demand for biomass in a 100% renewable energy system does not exceed the resource available.**
  In line with this, it is important to quantify the residual resource available and subsequently develop different biomass resource scenarios for the future: this can inform the debate surrounding the amount of biomass that will be available for a 100% renewable energy system. In addition, industry currently consumes a very large proportion of the biomass in the 100% renewable scenarios created in this study (~35-40%). Therefore, a study should be carried out identifying how much of the industry demand can be converted to either district heating or electricity, so more abundant renewable resources can be used instead of biomass.

8.2 Key Recommendations

- **Actions towards a 100% renewable energy system can begin today.**
  Numerous technologies which are recommended in this study between now and 2020 are already commercially available today. These include energy efficiency, the installation of wind turbines, heat pumps in rural houses, district heating in urban buildings, and the expansion of electric vehicles and public transport.

- **The LCR has a unique motivation and opportunity to develop and brand itself as a 100% renewable energy region.**
  Firstly, the LCR can build a very positive brand for the region associated with innovation, sustainability, and community collaboration. Secondly, with the Limerick regeneration project currently underway, there is an opportunity to develop an energy exemplar project such as a low-temperature district heating network. Thirdly, recent statistics indicated that "at administrative county level Limerick City had the highest unemployment rate in 2011" [1], so creating 2,000 more local jobs based on the actions outlined in this report should be of particular interest to the LCR.

- **The local authorities in the LCR can play a key role in the transition to a sustainable energy system using very long-term (i.e. ownership and operation of infrastructure) or short-term (i.e. facilitating and networking) methods.**

  For example, a simple start is to bring the key energy stakeholders together to develop an energy steering group for the region, which is made up of key decision makers, local authority members, local politicians, and community groups. Initial meetings should be used to assess the appetite for developing the Limerick-Clare region as a 100% renewable region (or whatever the target may be), as it will only be possible with the support, involvement, and collaboration between all sectors of the community. If this goal is to be fulfilled, resources will then need to be allocated from all parties to create a management team to run the project, including expertise, time, and financial support. A detailed description of the working group required to run such a project is available from both SEAI [2] and the IEA [3]. Other initial steps could be an energy efficiency network connecting consumers with reliable tradesmen or quantifying the energy demand in the region in more detail (i.e. using audits or heat atlases), so other organisations can also create energy alternatives in the region.

- **National government policies must allow for socio-economic alternatives to be implemented at local level.**

  Like any local planning authority, clear support from central government is a key advantage when implementing local initiatives. However, under current policies, subsidies, and taxes, the most socio-economic alternatives identified in this study may not be the most business-economic alternatives. Therefore, it is important that the Irish government structure their policies so that the most socio-economic alternatives are implemented at a local level. For example, this may require a subsidy for heat pumps in rural homes. An existing policy which illustrates this is the new REFIT of €100-150/MWh in Ireland to support approximately 50 MW of CHP based on anaerobic digestion [4, 5]. This could be utilised in the Limerick Clare region to support the expansion of district heating. From the results in this study, it is not possible to identify how policies will need to be reorganised to support the scenario recommended, but during the implementation phase this will become apparent and so national policy support will be essential.

8.3 Key Messages

- **This study is only a snapshot in time of how the energy system in the Limerick-Clare Region could evolve.**
  Naturally, knowledge will continuously change and so it is important for the region to regularly update this strategy to account for new knowledge. For example, future studies could contain a more detailed breakdown of the transport sector and more knowledge about the biomass resource in the region. Similarly, the scenarios presented in this report are not a prediction of the future, but instead they are designed to outline the consequences of choosing different alternatives. Hence, the results are provided to inform the debate, but it will be local actors and citizens who will decide what the future energy system in the LCR will be.

- **The LCR can be a living laboratory test-case for a national conversion to a sustainable energy system.**
  The results are not only relevant to the LCR, but are indicative of the type of actions required throughout the Irish energy system to integrate more renewable energy, reduce GHG emissions and increase jobs. Therefore, by being a first mover, the LCR can demonstrate how other regions in Ireland can transition to a 100% renewable energy system also.

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10 Appendices

Appendix I. Hourly Distributions

When simulating the operation of the LCR energy system, the EnergyPLAN tool uses an hourly time step for electricity, heat, and transport demand. Below is an overview of how these hourly distributions are constructed.

Electricity

The annual electricity demand for the various scenarios considered is available from the energy balance completed [13].For the hourly distribution, data for Ireland from 2007 is used to estimate the hourly pattern of the electricity consumed in the LCR [97]. The year 2007 was chosen, since this is the year currently recommended by EirGrid, with more recent years showing abnormalities due to the global economic recession [98]. The hourly demand in Ireland was then proportioned to the LCR based on the ratio between the winter peak demands for each.

Each year, EirGrid produce their transmission forecast for the upcoming 6 years. From this report it is possible to obtain the winter peak electricity demand for the individual transmission interface stations (TIS) in Ireland, which are the substations that connect the transmission network to the distribution network. There are ten TIS in the LCR, which are illustrated in Figure 38 and Table 9. The winter peak capacity forecasted for these TIS points was therefore obtained from EirGrid's Transmission Forecast Statement for the years 2011-2017 [88] and projected forward based on their growth patterns for three more years until 2020. The final 2020 winter peak electricity demand is displayed in Table 9, which is 400 MW.

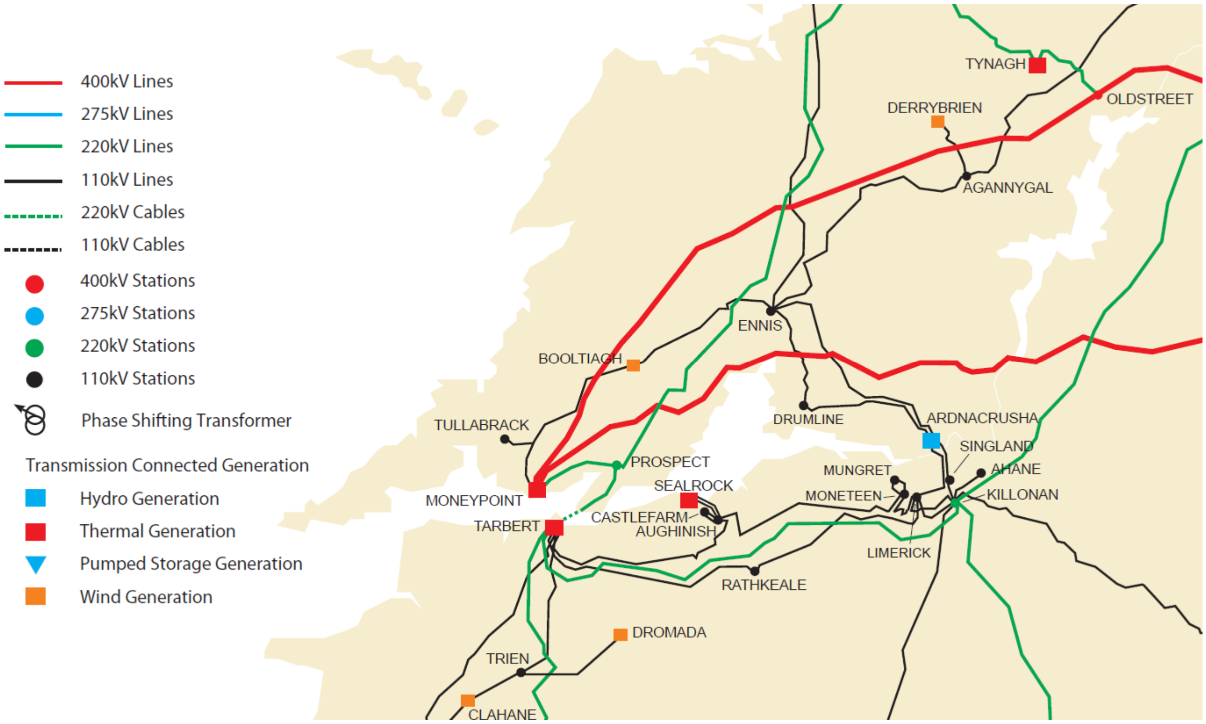

Figure 38: Transmission interface stations located in the Limerick Clare Region [99].

Table 9: Forecasted winter peak electricity demand in Limerick and Clare for 2011-2017 [88] and the projected data for 2018-2020.

Transmission Interface Station	Year									
Name	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Ahane	4.7	4.8	4.8	5.0	5.1	5.2	5.2	5.3	5.4	5.5
Castlefarm	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Limerick	73.9	75.2	75.9	77.9	80.1	81.1	71.4	72.8	74.3	75.8
Mungret	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7	25.7
Rathkeal	25.8	26.3	26.5	27.2	28.0	28.3	28.7	29.3	29.9	30.5
Singland	15.4	15.7	15.9	16.3	16.7	16.9	17.2	17.5	17.9	18.3
Limerick Total	189.5	191.7	192.8	196.1	199.6	201.2	192.2	194.7	197.1	199.7
Ardnacrusha	60.4	61.5	62.0	63.7	65.5	66.3	67.2	68.5	69.9	71.3
Drumline	25.4	35.8	36.1	36.8	37.5	37.9	38.2	39.0	39.7	40.5
Ennis	63.5	64.6	65.1	66.9	68.7	69.7	70.6	72.0	73.5	74.9
Tullabrack	11.5	11.7	11.8	12.1	12.5	12.6	12.8	13.1	13.3	13.6
Clare Total	160.8	173.6	175.0	179.5	184.2	186.5	188.8	192.6	196.4	200.4
LCR Total	**350.3**	**365.3**	**367.8**	**375.6**	**383.8**	**387.7**	**381.0**	**387.2**	**393.6**	**400.1**

In 2007, the winter peak in Ireland was 5054 MW, while in the LCR it is forecasted to be 400 MW in 2020. After proportioning the data in this way and using it to simulate the total forecasted electricity demand of 2132 GWh in the LCR in 2020 (under the *NEEAP/NREAP* scenario), the winter peak in the results was 378 MW, which is 5.5% less than 400 MW. This was deemed acceptable in this study.

Heat

The hourly heating distribution is not an essential input for the reference energy system, where there is very little interaction between the electricity, heat, and transport sectors. However, as outlined in section 1, a 100% renewable energy system will depend on the flexibility created by integrating these sectors. Hence, when evaluating 100% renewable energy scenarios for 2050, it is important to consider how the heating demand varies on an hourly basis. Currently however, there are no large-scale district heating facilities in Ireland and almost all homes are heated using individual boilers. Therefore, no hourly heating demands were obtained for this study and instead, the hourly distribution was created using degree day data from Met Éireann [100].

Degree day data is commonly used to as an indication of energy consumption within buildings. In Ireland the setpoint used is 15.5°C, which is applied as follows: the temperature within a building is usually 2-3°C more than outside, so when the outside temperature is 15.5°C, the inside of a building is usually 17.5°C to 18.5°C. Therefore, once the temperature drops below this 15.5°C outside-temperature setpoint, the inside temperature drops below 17.5/18.5°C and the space heating within a building is usually turned on. Note that this 15.5°C setpoint is specifically for Ireland and it can change depending on a number of factors such as the climate and the typical level of house insulation [100]. A full explanation about the calculation and application of HDD data can be obtained from [100, 101].

For the heat demand, an annual distribution with a resolution of 1 hour is required, but the degree day recorded at Irish weather stations is only recorded on a daily basis. Therefore, this 1 day data had to be converted into hourly readings. To do this, an average daily heat distribution from a Danish district heating system was applied to the data. As district heating is common in Denmark, hourly data could be easily obtained over a 24 hour period and it was assumed that Ireland would have a similar daily distribution in its heat demands due to their climatic similarities. The daily distribution used is the average daily cycle on the Aalborg district heating network in 2008.

Finally, by obtaining the HDD data, the level of heat required each day within a building can be estimated. However, this only considered the space heating distribution and not the hot water distribution. Therefore, a heat distribution which accounted for both space heating and hot water demand had to be constructed. For the summer months, it is assumed that space heating would not be required: it is assumed that the heat absorbed by the building during warm temperatures, and also the building's occupants, would keep the building warm during colder temperatures. Therefore, during the summer hot water is the only heating demand. It is also assumed that hot water is a constant demand each day for the entire year, as people tend to use a consistent amount of water regardless of temperature or time of year. The BERR in the UK completed a report in relation to domestic hot water and space heating, which indicated that the ratio of space heating to hot water heating in the home is 7:3 [102]. Therefore, as seen in Figure 39, for the heat distribution a 30% constant bandwidth was placed at the base representing hot water demand, and a 70% demand was placed on top (based on degree day data) representing the space heating requirements. Figure 39 represents the heat distribution constructed for modelling the heat demand in the reference model of the Limerick-Clare region, based on HDD data from 2009.

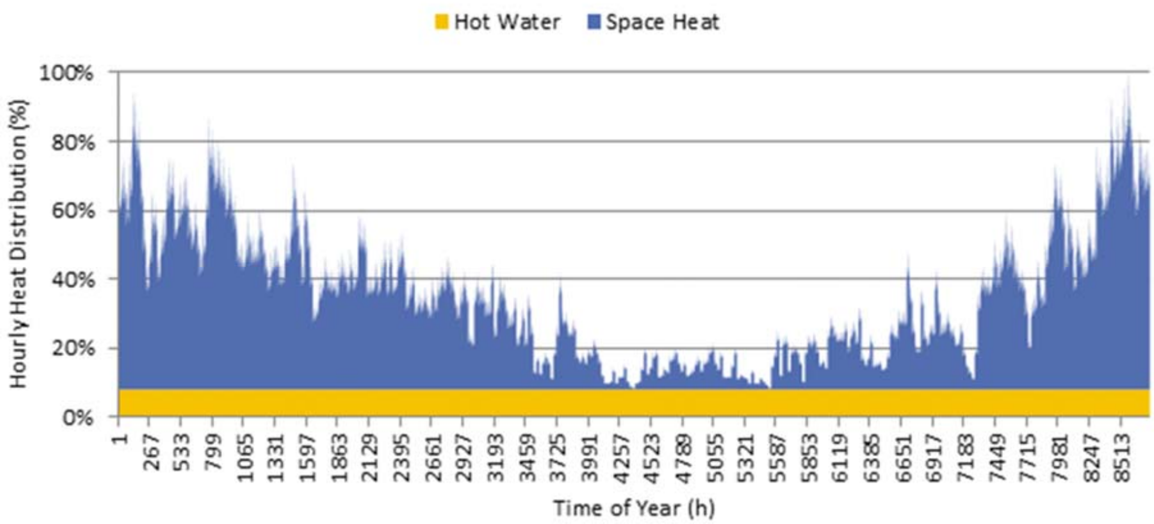

Figure 39: Hourly heat distribution based on 2009 daily HDD data from the Limerick Clare region and a typical 24-hourly distribution from Aalborg's (Denmark) district heating network.

This methodology was previously validated by comparing the hourly heat demand for Aalborg's district heating network to the hourly distribution calculated using degree day data.

Transport

Similar to the heat sector, the hourly distribution of the transport demand is not an essential piece of data for the existing energy system in Ireland. However, as outlined in section 1, future renewable energy systems will require the integration of the electricity, heat, and transport sectors. Hence, when evaluating alternatives, particularly electric vehicles, hourly data for the transport demand is an important consideration.

Transport demand data on an hourly resolution is very rare and relatively difficult to obtain compared to hourly heat data, and especially compared to hourly electricity data. Therefore, in this study, the hourly transport demand was based on data from the National Household Survey of Transport in the USA [103], which surveyed 69,817 households and approximately 260,000 people about the time of day and week which they travel [104]. As outlined in Figure 40, there is a significant variation in the transport demand throughout the day, but the cycle is similar from one day to the next. The data is only available for one week, so this is repeated over the course of one year.

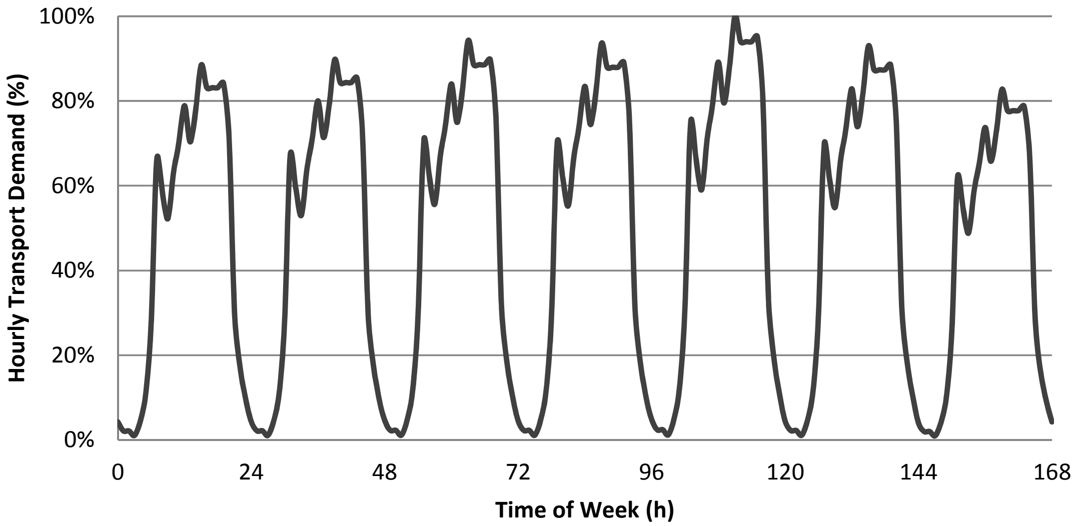

Figure 40: Hourly transport distribution based on data from the USA [103, 104].

Appendix II. Costs

Fuel Costs

Fuel costs were based on forecasts from the International Energy Agency [105] and the Danish Energy Agency [7]. It was assumed that peat is the same cost as coal, but according to industry experts peat actually costs approximately €11/GJ [79]. Hence, there is a slight underestimation of fuel costs, but this was deemed acceptable since peat only accounts for approximately 1% of energy consumed in Ireland in 2020 [14].

Table 10: High, medium, and low fuel prices assumed [7, 105].

2009-€/GJ	Oil (US$/bbl)	Natural Gas	Coal	Fuel Oil	Diesel & Petrol	Jet Fuel	Straw	Wood Chips	Wood Pellets	Energy Crops
2011 (Low)	82.0	5.9	2.7	8.8	11.7	12.7	3.5	4.5	9.6	4.7
2020 (Medium)	107.4	9.1	3.1	11.9	15.0	16.1	3.9	5.1	10.2	4.7
2030	118.9	10.2	3.2	13.3	16.6	17.6	4.3	6.0	10.9	5.2
Projected assuming the same trends as in 2020-2030										
2040	130.5	11.2	3.3	14.7	18.1	19.1	4.7	6.8	11.5	5.7
2050 (High)	142.0	12.2	3.4	16.1	19.6	20.6	5.1	7.6	12.2	6.3

Fuel handling costs were obtained from the Danish Energy Agency [7].They represent the additional costs of handling and storing fuels for different types of consumers as well as expected profit margins.

Table 11: Fuel handling costs[7].

2009 - €/GJ Fuel	Centralised Power Plants	Decentralised Power Plants & Industry	Consumer
Natural Gas	0.412	2.050	3.146
Coal	-	-	-
Fuel Oil	0.262	-	-
Diesel/Petrol	0.262	1.905	2.084
Jet Fuel	-	-	0.482
Straw	1.754	1.216	2.713
Wood Chips	1.493	1.493	
Wood Pellets	-	0.543	3.256
Energy Crops	1.493	1.493	

Production Unit Costs

All of the investment costs in this study are based on 2020 estimates (see Table 12), which is conservative for the 2050 scenarios since the cost of many technologies will most likely fall between 2020 and 2050.

Table 12: Technology costs for centralised production units the energy system analysis [11, 44, 67, 79, 106-109].

Production Type	Unit	Investment (M€/unit)	Lifetime (Years)	Fixed O&M (% of Investment)
Solar Thermal	TWh/year	440	20	0.001%
Thermal Storage	GWh	2.5	20	0.70%
CHP Plants	MWe	0.84	25	2.30%
Large-Scale Heat Pumps	MWe	2.7	20	0.20%
Centralised Boilers	MWth	0.15	20	3.00%
Coal Power Plant	MWe	1.98	30	1.77%
CCGT Power Plant	MWe	0.68	25	1.51%
Nuclear	MWe	3	25	3.74%
Wind Onshore	MWe	1.25	20	3.00%
Wind Offshore	MWe	2.3	20	2.90%
Photovoltaic	MWe	2.6	30	0.77%
Wave Power	MWe	4.285	20	3.50%
Tidal	MWe	3.5	20	3.00%
River Hydro	MWe	1.9	50	2.70%
Hydro Power	MWe	1.9	50	2.70%
Hydro Storage	GWh	7.5	50	1.50%
Hydro Pump	MWe	0.6	50	1.50%
Geothermal	MWe	2.63	20	3.42%
Electrolyser	MWe	0.57	20	2.46%
Hydrogen Storage	GWh	10	30	0.50%
Pump	MWe	0.6	50	1.50%
Turbine	MWe	0.6	50	1.50%
Pump Storage	GWh	7.5	50	1.50%
Biogas Upgrade	MW	0.278	15	1.94%
Waste CHP	TWh/year	250.45	20	1.82%
Absorption Heat Pump	MWth	1.9	25	2.42%
Biogas Plant	TWh/year	376.5	20	11.25%
Gasification Plant	MWe	2.6	20	2.08%
Biodiesel Plant	MWe	0.535	20	5.19%
Biopetrol Plant	MWe	1.42	20	5.00%

The cost of implementing energy savings in Ireland in 2020 is from [110]. These were included for 2050, but since the energy demand is the same in all 2050 scenarios, the impact is not portrayed in any comparisons. An 3% interest rate is used when investment costs are converted into annual costs.

Individual Heating Costs

Table 13: Individual heating unit costs assumed in this study [12].

Parameter	Oil boiler	Natural gas boiler	Biomass boiler	Heat pump air-to-water	Heat pump brine-to-water	Electric heating	District heating substation
Capacity of one unit (kW_{th})	15-30	3-20	5-20	10	10	5	10
Annual average efficiency (%)	100	100-104	87	330	350	100	98
Technical lifetime (years)	20	22	20	20	20	30	20
Specific investment (1000€/unit)	6.6	5	6.75	12	16	4	2.5
Fixed O&M (€/unit/year)	270	46	25	135	135	50	150
Variable O&M (€/MWh)	0.0	7.2	0.0	0.0	0.0	0.0	0.0

Table 14: District heating network costs assumed in this study [12].

Technology	Low-temperature DH network
Heat density an consumer (TJ/km^2 land area)	45-50
Net loss (%)	13-16
Average Technical lifetime (years)	40
Average Investment costs (1000 €/TJ)	145
Average Fixed O&M (€/TJ/year)	1100
Branch Piping (1000€/substation)	3

Vehicle Costs

Table 15: Vehicle costs assumed in this study [80, 111].

Vehicle	Fuel	Investment Costs (€/vehicle)	O&M (% of Invest)
Cars	Petrol/Diesel	12,151	7.70%
	Electric	12,971	11.16%*
	EV Chargers	1,000	0.00%
	Bio-methanol	14,104	6.55%
Buses/Trucks	Diesel	161,074	1.23%
	Bio-methanol	163,960	1.20%

***Battery costs are included in the annual operation and maintenance costs.**

Appendix III. Final Energy Consumption for the 2020 and 2050 Reference Scenarios

Table 16: Final energy consumption in GWh for the 2010, 2020, and 2050 reference scenarios [13, 14].

Sector	Fuel Type	2010 (GWh)	2020 (GWh)		2050 (GWh)	
			Baseline	NEEAP/ NREAP	Baseline	NEEAP/ NREAP
Industry	Coal	117	115	115	112	112
Industry	Peat	0	0	0	0	0
Industry	Oil	870	1,015	790	1,449	551
Industry	Natural Gas	528	697	677	1,204	1,124
Industry	Renewables	182	174	378	148	967
Industry	Electricity	669	858	856	1,428	1,418
Industry	Total	2,365	2,859	2,817	4,341	4,172
Transport Sub	*Private Car Petrol*	*1,038*	*1,074*	*875*	*1,183*	*387*
Transport Sub	*Private Car Diesel*	*545*	*494*	*455*	*340*	*185*
Transport Sub	*Private Car Renewables (Biofuels)*	*77*	*114*	*323*	*226*	*1,062*
Transport Sub	*Private Car Electric*	*0*	*0*	*31*	*0*	*126*
Transport Sub	*Private Car LPG*	*1*	*0*	*0*	*0*	*0*
Transport Sub	*Road Freight Diesel*	*617*	*977*	*901*	*2,058*	*1,752*
Transport Sub	*Public Service Petrol*	*25*	*16*	*13*	*16*	*13*
Transport Sub	*Public Service Diesel*	*94*	*85*	*78*	*57*	*30*
Transport Sub	*Rail Diesel*	*5*	*5*	*5*	*5*	*5*
Transport Sub	*Rail Electric*	*0*	*0*	*0*	*0*	*0*
Transport Sub	*Aviation Jet Fuel*	*611*	*826*	*826*	*1,469*	*1,470*
Transport Sub	*Unspecified (Petrol)*	*113*	*126*	*102*	*165*	*72*
Transport Sub	*Unspecified (Diesel)*	*372*	*342*	*315*	*251*	*144*
Transport Sub	*Unspecified (FuelOil)*	*0*	*0*	*0*	*0*	*0*
Transport Sub	*Fuel Tourism (Petrol)*	*0*	*0*	*0*	*0*	*0*
Transport Sub	*Fuel Tourism (Diesel)*	*0*	*0*	*0*	*0*	*0*
Transport Oil	*Petrol*	*1,176*	*1,215*	*990*	*1,363*	*472*
Transport Oil	*Diesel*	*1,634*	*1,903*	*1,755*	*2,710*	*2,117*
Transport Oil	*Jet Fuel*	*611*	*826*	*826*	*1,469*	*1,470*
Transport Oil	*Other (LPG & FuelOil)*	*1*	*0*	*0*	*0*	*0*
Transport	Oil	3,422	3,944	3,571	5,543	4,058
Transport	Renewables	77	114	323	226	1,062
Transport	Electricity	0	0	31	0	126
Transport	Total	3,498	4,058	3,925	5,768	5,246
Residential	Coal	200	61	52	0	0
Residential	Peat	204	112	103	0	0
Residential	Oil	1,019	1,172	879	1,631	459
Residential	Natural Gas	571	596	399	671	399
Residential	Renewables	47	35	74	2	156
Residential	Electricity	589	576	534	537	370
Residential	Total	2,630	2,553	2,042	2,841	1,385
Commercial	Coal	0	0	0	0	0
Commercial	Peat	0	0	0	0	0
Commercial	Oil	354	222	93	0	0
Commercial	Natural Gas	317	440	292	809	216
Commercial	Renewables	13	11	89	6	317
Commercial	Electricity	568	626	579	801	611

Commercial	Total	1,251	1,299	1,053	1,616	1,144
Agriculture	Coal	0	0	0	0	0
Agriculture	Peat	0	0	0	0	0
Agriculture	Oil	246	330	330	580	580
Agriculture	Natural Gas	0	0	0	0	0
Agriculture	Renewables	0	0	0	0	0
Agriculture	Electricity	52	85	85	182	182
Agriculture	Total	299	415	415	762	762
		TOTAL ENERGY				
All	Coal	316	177	168	112	112
All	Peat	204	112	103	0	0
All	Oil	5,911	6,683	5,663	9,203	5,649
All	Natural Gas	1,416	1,733	1,368	2,684	1,739
All	Renewables	318	334	864	382	2,502
All	Electricity	1,878	2,145	2,085	2,948	2,707
All	Total	10,044	11,184	10,252	15,328	12,709
		TOTAL ENERGY INCLUDING FUEL FOR ELECTRICITY GENERATION				
All	Coal	822	824	588	1,181	532
All	Peat	490	331	251	19	0
All	Oil	5,971	6,683	5,663	9,203	5,649
All	Natural Gas	3,181	3,707	2,693	5,286	3,292
All	Renewables	966	1,145	2,060	1,594	4,183
All	Total	11,431	12,689	11,255	17,283	13,656

Appendix IV. Demand and Supply for the 2020 Scenarios

Table 17: Breakdown of the electricity supply and demand by sector for the 2020 scenarios considered. The demands have been derived from the Energy and Emissions Balance report [13], while the majority of the technical operation data has been obtained from the Danish Energy Agency [6, 11].

Sector	Input	2020 Scenarios			
		Baseline	NEEAP/NREAP	DH&HP	LCR 2020 (DH&HP+RE)
Electricity Demand	Electricity Demand (TWh)	2.145	2.085	2.018	2.018
	Including Electric Heating (TWh)	*0.29*	*0.268*	*0.201*	*0.201*
	Including Electric Vehicles (TWh)	*0*	*0.031*	*0.031*	*0.031*
Power Plants and District Heating	Centralised Power Plants				
	Condensing PP (MW)	446	479	473	478
	Condensing PP Efficiency (%)	47%	47%	47%	47%
	DH Demand (TWh)	0	0	0.067	0.067
	CHP (MW)	0	0	25	25
	CHP Electricity Efficiency (%)	0	0	52%	52%
	CHP Heat Efficiency (%)	0	0	39%	39%
	Thermal Storage (GWh)	0	0	1.77	1.77
	Heat Pump (MW)	0	0	0	1.5
	Heat Pump COP	0	0	3	3
	Boiler (MW)	0	0	30	30
	Boiler Efficiency (%)	0	0	90%	90%
	Solar (TWh)	0	0	0	0.006
	Solar Storage (GWh)	0	0	0	0.133
	Decentralised Power Plants				
	DH Demand (TWh)	0	0	0.131	0.131
	CHP (MW)	0	0	40	40
	CHP Electricity Efficiency (%)	0	0	52%	52%
	CHP Heat Efficiency (%)	0	0	39%	39%
	Thermal Storage (GWh)	0	0	3.44	3.44
	Heat Pump (MW)	0	0	0	3.5
	Heat Pump COP	0	0	3	3
	Boiler (MW)	0	0	59	59
	Boiler Efficiency (%)	0	0	90%	90%
	Solar (TWh)	0	0	0	0.012
	Solar Storage (GWh)	0	0	0	0.258
Individual Heating	Coal				
	Boiler Input (TWh)	0.173	0.155	0.109	0.109
	Efficiency (%)	65%	65%	65%	65%
	Oil				
	Boiler Input (TWh)	1.3921	0.973	0.682	0.682
	Efficiency (%)	80%	80%	80%	80%
	Natural Gas				
	Boiler Input (TWh)	1.036	0.691	0.484	0.484
	Efficiency (%)	89%	89%	89%	89%
	Biomass				
	Boiler Input (TWh)	0.038	0.134	0.134	0.134
	Efficiency (%)	70%	70%	70%	70%

	Heat Pump				
	Heat Demand (TWh)	0.0065	0.023	0.250	0.250
	Efficiency (%)	3.26	3.26	3.255	3.255
	Electric Heating				
	Heat Demand (TWh)	0.289	0.268	0.201	0.201
	Efficiency (%)	100%	100%	100%	100%
	Solar				
	Heat Production (TWh)	0.002	0.007	0.007	0.094
Industry	Coal (TWh)	0.115	0.115	0.115	0.115
	Oil (TWh)	1.015	0.790	0.790	0.790
	Natural Gas (TWh)	0.697	0.677	0.677	0.677
	Biomass (TWh)	0.174	0.378	0.378	0.378
	Heat Production (TWh)	0	0	0	0
	Electricity Production (TWh)	0.008	0.008	0.008	0.008
Intermittent Renewable Electricity Sources	Wind				
	Installed Capacity (MW)	184	330	330	330
	Electricity Generated (TWh)	0.51	0.91	0.91	0.91
	PV				
	Installed Capacity (MW)	0	0	0	25
	Electricity Generated (TWh)	0	0	0	0.026
	Wave				
	Installed Capacity (MW)	0	0	0	0
	Electricity Generated (TWh)	0	0	0	0
	Tidal				
	Installed Capacity (MW)	0	0	0	10
	Electricity Generated (TWh)	0	0	0	0.037
	Hydro				
	Installed Capacity (MW)	86	86	86	86
	Electricity Generated (TWh)	0.32	0.32	0.32	0.32
Electricity Storage	Hydrogen				
	Electrolyser (MW)	0	0	0.0	0.0
	Efficiency	0	0	73%	73%
	Hydrogen Storage	0	0	0	0
	PHES				
	Pump (MW)	0	0	0	0
	Turbine (MW)	0	0	0	0
	Pump Efficiency (%)	0	0	0	0
	Turbine Efficiency (%)	0	0	0	0
	Storage Capacity (GWh)	0	0	0	0
Transport	Jet Fuel (TWh)	0.826	0.826	0.826	0.826
	Diesel (TWh)	2.233	2.085	2.085	2.085
	Petrol (TWh)	1.215	0.990	0.990	0.990
	Hydrogen (TWh)	0	0	0	0
	Electricity Smart Charge (TWh)	0	0.031	0.031	0.031

	Grid to Battery Connection (MW)	0	76	76	76
	Battery Storage Capacity (GWh)	0	0.38	0.38	0.38
Biofuels	Biogas (TWh)	0	0	0	0.459
	Biodiesel (TWh)	0.08	0.226	0.226	0.226
	Bioethanol (TWh)	0.034	0.097	0.097	0.097
	Biojetfuel (TWh)	0	0	0	0

Appendix V. 100% Renewable Energy Scenarios in 2050

The study includes a long-term 100% renewable energy vision for the Limerick-Clare Region (LCR). The following is a non-exhaustive list of the technologies considered during the study:

- Intermittent renewable energy such as wind, wave, tidal, PV
- Hydro
- Biomass
- Biomass gasification
- Bioethanol
- Biodiesel
- Biogas
- Biomass hydrogenation for liquid fuels in transport
- Electric vehicles
- Pumped hydroelectric energy storage
- Hydrogen:
    - Electrolysers
    - Storage
- Individual heating systems:
    - Heat pumps
    - Biomass boilers
    - Electric Heating
    - Solar panels
- District heating
- District heating production plants:
    - Combined heat and power
    - Centralised boilers
    - Centralised thermal storage
    - Large-scale heat pumps
    - Centralised solar thermal plants
    - Surplus industrial heat
    - Surplus gasification heat

After considering each of these technologies, 10 different scenarios were investigated in 2050 to ensure that short-term actions fit with the long-term objective:

1. **NEEAP/NREAP 2050:** A 'business-as-usual' 2050 scenario representing what will occur if the trends between 2010 and 2020 in the *NEEAP/NREAP 2020* scenario continue to 2050. It acts as a 'fossil-fuel' reference, which the alternative 100% renewable energy scenario are compared with.
2. **District Heating & Heat Pumps (DH&HP):** In this scenario, all urban households are converted to district heating and all rural households are converted to ground source heat pumps. The district

heating network is provided with heat from CHP plants, boilers, and thermal storage. Electricity is produced from power plants and CHP plants using both biomass and biogas, along with wind power, 250 MW wave, 250 MW of PV, and 30 MW of tidal. Transport demands are met using electric vehicles (75% of private cars) and synthetic liquid fuels such as methanol and DME (see Figure 26). Wind power is increased until approximately 10% of electricity produced from wind cannot be integrated into the Limerick-Clare energy system. Also, the power plant capacity is equal to the peak electricity demand on the system, to ensure there is always sufficient capacity available.

3. **DH&HP+RE:** This is the same as the DH scenario, expect renewable energy which can now be utilised with the introduction of DH is also added. This includes centralised heat pumps which use surplus wind energy, centralised solar thermal plants, and surplus industrial heat.
4. **DH&HP+RE&SmallPHES:** This is the same as the DH+RE scenario, but with the addition of a relatively small pumped hydroelectric energy storage (PHES) plant: It has a 50 MW pump, 50 MW turbine and a 0.5 TWh storage.
5. **DH&HP+RE&LargePHES:** This is the same as the DH+RE scenario, but with the addition of a relatively large PHES plant: It has a 600 MW pump, 300 MW turbine and a 5 TWh storage. The pump and turbine capacities are different since they provide different functions: the pump absorbs surplus wind while the turbine replaces power plant production [48].
6. **LCR 2050 (DH&HP+RE&H2):** This is the recommended scenario for the LCR for 2050. It is the same as the DH+RE scenario, but with the addition of hydrogen storage facility: this hydrogen can then be used in the CHP plants or the power plants. It has a 300 MW electrolyser and it uses the existing hydrogen storage, which is already available due to the biomass gasification process used to create liquid fuels for the transport sector (see Figure 26).
7. **Heat Pumps (HP):** This is the same as the DH scenario, but instead of district heating in the urban households, air-to-water heat pumps are used. Previous research has indicated that this is the most efficient and economical alternative to district heating [68, 69, 112].
8. **HP+SmallPHES:** This is the same as the HP scenario, but with the addition of a relatively small PHES plant: It has a 50 MW pump, 50 MW turbine and a 0.5 TWh storage.
9. **HP+LargePHES:** This is the same as the HP scenario, but with the addition of a relatively large PHES plant: It has a 600 MW pump, 300 MW turbine and a 5 TWh storage. The pump and turbine capacities are different since they provide different functions: the pump absorbs surplus wind while the turbine replaces power plant production [48].

10. **HP+H2:** This is the same as the HP scenario, but with the addition of hydrogen storage facility: this hydrogen can then be used in the CHP plants or the power plants. It has a 300 MW electrolyser and it uses the existing hydrogen storage, which is already available due to the biomass gasification process (see Figure 26).

The results in Figure 41 indicate that both the district heating and heat pump scenarios will lead to a similar demand for biomass in a 100% renewable energy system. Also, pumped hydro is not as effective as hydrogen storage at reducing the biomass demand in both scenarios.

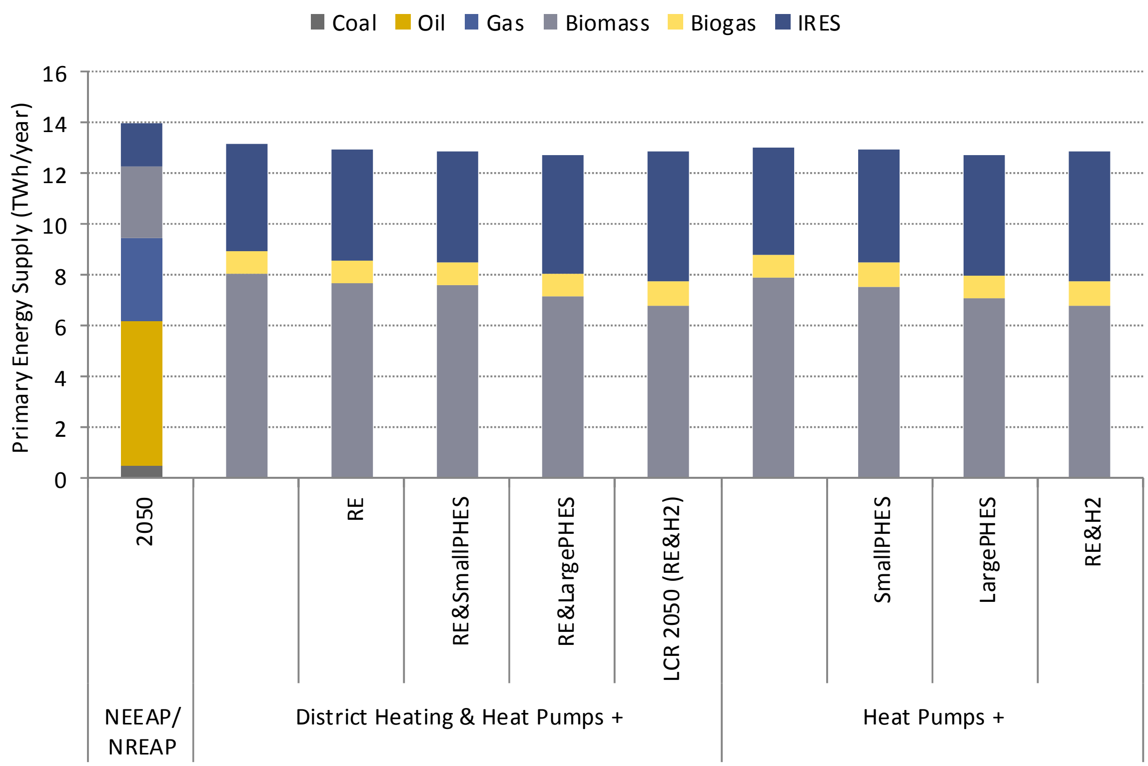

Figure 41: Primary energy supply for the 10 different scenarios considered in 2050.

In terms of costs (see Figure 42), the district heating scenario is approximately 4% cheaper than the heat pump scenario. The results remain the same when the fuel and CO_2 prices are increased to 2050 levels. The 100% renewable energy scenarios are approximately 20% more expensive than the fossil fuel reference using 2020 fuel prices, but they are only 2-5% more expensive when using 2050 fuel prices. Note that the investment costs were all based on 2020 prices for both of these assessments. This demonstrates how the energy system will evolve from a fuel based system to an investment based system, which suggests that is highly probable that renewable energy systems will become cheaper in the future if expected forecasts are correct (i.e. fuel prices increasing and investment cost reducing).

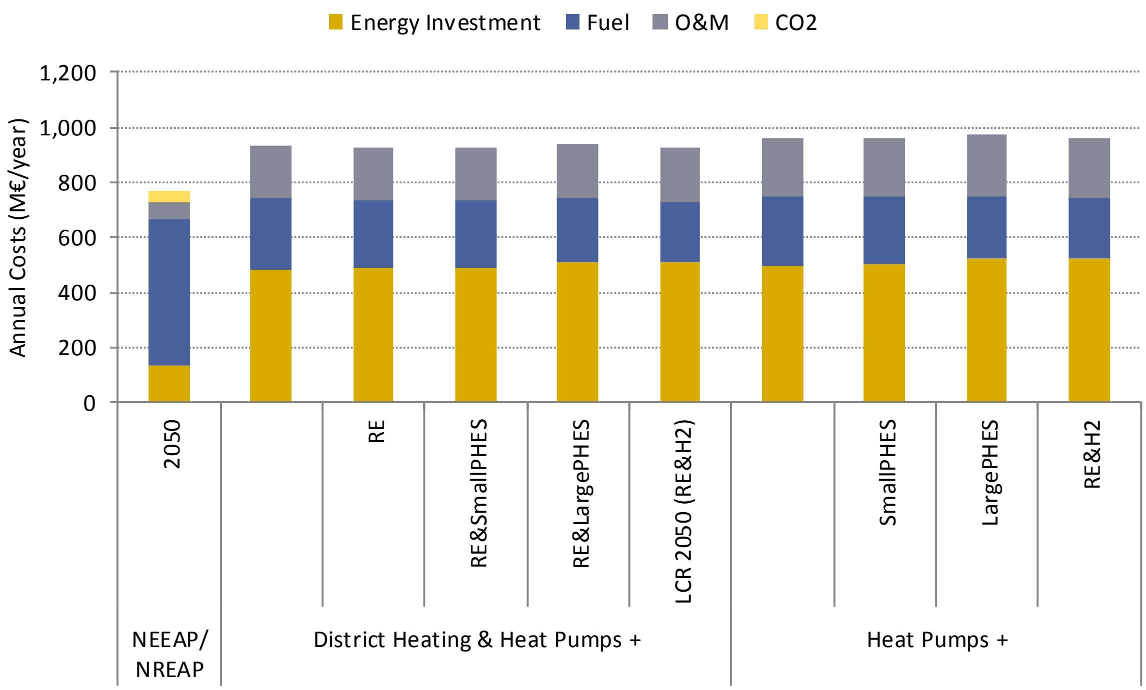

Figure 42: Annual costs using 2020 investment costs and forecasted 2050 fuel prices (Appendix II) for the 10 different scenarios considered in 2050.

Appendix VI. Demand and Supply for the Primary 2050 Scenarios

Table 18: Breakdown of the electricity supply and demand by sector for the 2050 scenarios with the lowest biomass demands and costs. The demands have been project based on the *NEEAP/NREAP 2020* scenario developed in the Energy and Emissions Balance report [13], while the majority of the technical operation data has been obtained from the Danish Energy Agency [6, 11].

Sector	Input	2050 Scenarios		
		NEEAP/NREAP 2050	LCR 2050 (DH&HP+RE&H2)	HP+RE&H2
Electricity Demand	Electricity Demand (TWh)	2.707	2.912	2.912
	Including Electric Heating (TWh)	*0.211*	*0.074*	*0.074*
	Including Electric Vehicles (TWh)	*0.126*	*0.468*	*0.468*
Power Plants and District Heating	Centralised Power Plants			
	Condensing PP (MW)	436	601	787
	Condensing PP Efficiency (%)	57.5%	61.5%	61.5%
	DH Demand (TWh)	0	0.270	0
	CHP (MW)	0	40	0
	CHP Electricity Efficiency (%)	0	52.0%	0
	CHP Heat Efficiency (%)	0	39.0%	0
	Storage (GWh)	0	5.90	0
	Heat Pump (MW)	0	10	0
	Heat Pump COP	0	4	0
	Boiler (MW)	0	97.2	0
	Boiler Efficiency (%)	0	90%	0
	Solar (TWh)	0	0.040	0
	Solar Storage (GWh)	0	0.885	0
	Decentralised Power Plants			
	DH Demand (TWh)	0	0.524	0
	CHP (MW)	0	120	0
	CHP Electricity Efficiency (%)	0	52.0%	0
	CHP Heat Efficiency (%)	0	39.0%	0
	Storage (GWh)	0	11.45	0
	Heat Pump (MW)	0	20	0
	Heat Pump COP	0	4	0
	Boiler (MW)	0	189.6	0
	Boiler Efficiency (%)	0	90%	0
	Solar (TWh)	0	0.079	0
	Solar Storage (GWh)	0	1.72	0
Individual Heating	Coal			
	Boiler Input (TWh)	0	0	0
	Efficiency (%)	65%	0.65	0.65
	Oil			
	Boiler Input (TWh)	0.459	0	0
	Efficiency (%)	80%	0.8	0.8
	Natural Gas			
	Boiler Input (TWh)	0.615	0	0
	Efficiency (%)	89%	0.89	0.89
	Biomass			
	Boiler Input (TWh)	0.388	0.106	0.106
	Efficiency (%)	70%	70%	70%

	Heat Pump			
	Heat Demand (TWh)	0.066	0.599	1.334
	Efficiency (%)	3.72	3.72	3.80
	Electric Heating			
	Heat Demand (TWh)	0.211	0.074	0.074
	Efficiency (%)	100%	100%	100%
	Solar			
	Heat Production (TWh)	0.019	0.074	0.074
Industry	Coal (TWh)	0.112	0	0
	Oil (TWh)	0.551	0	0
	Natural Gas (TWh)	1.124	0	0
	Biomass (TWh)	0.967	2.754	2.754
	Heat Production (TWh)	0	0.270	0
	Electricity Production (TWh)	0.008	0.008	0.008
Intermittent Renewable Electricity Sources	Wind			
	Installed Capacity (TWh)	490	1280	1340
	Electricity Generated (TWh)	1.353	3.53	3.70
	PV			
	Installed Capacity (TWh)	0	250	250
	Electricity Generated (TWh)	0	0.259	0.259
	Wave			
	Installed Capacity (TWh)	0	250	250
	Electricity Generated (TWh)	0	0.682	0.682
	Tidal			
	Installed Capacity (TWh)	0	30	30
	Electricity Generated (TWh)	0	0.111	0.111
	Hydro			
	Installed Capacity (TWh)	86	86	86
	Electricity Generated (TWh)	0.32	0.32	0.32
Electricity Storage	Hydrogen			
	Electrolyser (MW)	0	602	602
	Efficiency	0	73%	73%
	Hydrogen Storage	0	28.6	28.6
	PHES			
	Pump (MW)	0	0	0
	Turbine (MW)	0	0	0
	Pump Efficiency (%)	0	0	0
	Turbine Efficiency (%)	0	0	0
	Storage Capacity (GWh)	0	0	0
Transport	Jet Fuel (TWh)	1.470	0	0
	Diesel (TWh)	2.697	0	0
	Petrol (TWh)	0.472	0	0
	Hydrogen (TWh)	0	0	0
	Electricity Smart Charge (TWh)	0.126	0.468	0.468

	Grid to Battery Connection (MW)	304	542	542
	Battery Storage Capacity (GWh)	1.52	2.71	2.71
Biofuels	Output Biogas (TWh)	0	0.918	0.918
	Biodiesel (TWh)	0.744	0	0
	Bioethanol (TWh)	0.319	0	0
	Biojetfuel (TWh)	0	0	0
Synfuels	Biomass Inputted (TWh)	0	2.979	2.979
	Gasified Biomass Syngas (TWh)	0	2.400	2.400
	Hydrogen (TWh)	0	1.490	1.490

Appendix VII. EnergyPLAN Output Sheets

Baseline 2020

Input 0b. LCEP_Baseline_2020_Closed_30%.txt — The EnergyPLAN model 10.0 Test

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	1.86	Fixed imp/exp.	0.00
Electric heating	0.29	Transportation	0.00
Electric cooling	0.00	Total	2.14

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

Wind	184 MW	0.51	TWh/year	0.00	Grid
Offshore Wind	0 MW	0	TWh/year	0.00	stabili-
Wave Power	0 MW	0	TWh/year	0.00	sation
Tidal	0 MW	0	TWh/year	0.00	share
Hydro Power	86 MW	0.32	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	446		0.47		

Heatstorage: gr.2: 0 GWh gr.3: 0 GWh
Fixed Boiler: gr.2: 0.0 Per cent gr.3: 0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.01	0.00

Regulation Strategy:	Technical regulation no. 3	
KEOL regulation	00000000	
Minimum Stabilisation share	0.30	
Stabilisation share of CHP	1.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0.50	
Maximum import/export	0	MW

GB_2020_market_price_900high.txt

Addition factor	0.00	EUR/MWh
Multiplication factor	1.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	59	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

	Capacities	Storage	Efficie	
	MW-e	GWh	elec.	Th
Hydro Pump:	0	0	0.90	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biom
Transport	0.00	4.27	0.00	0.00
Household	0.17	1.39	1.04	0.04
Industry	0.12	1.01	0.70	0.17
Various	0.00	0.00	0.00	0.00

Output WARNING!!: (1) Critical Excess;

	District Heating										Electricity																		Exchange	
	Demand	Production									Consumption						Production							Balance					Payment	
	Distr. heating MW	Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Balance MW	Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp Million EUR
January	0	0	0	0	0	0	0	0	0	0	212	0	0	0	56	0	0	67	81	0	1	0	121	248	0	1	1	0	0	0
February	0	0	0	0	0	0	0	0	0	0	218	0	0	0	51	0	0	41	61	0	1	0	167	281	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	214	0	0	0	41	0	0	68	63	0	1	0	123	242	0	1	1	0	0	0
April	0	0	0	0	0	0	0	0	0	0	197	0	0	0	35	0	0	51	12	0	1	0	169	257	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	202	0	0	0	26	0	0	59	10	0	1	0	158	242	0	1	1	0	0	0
June	0	0	0	0	0	0	0	0	0	0	208	0	0	0	16	0	0	33	13	0	1	0	177	281	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	209	0	0	0	13	0	0	49	38	0	1	0	135	258	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0	210	0	0	0	13	0	0	61	37	0	1	0	125	240	0	1	1	0	0	0
September	0	0	0	0	0	0	0	0	0	0	215	0	0	0	18	0	0	44	18	0	1	0	172	268	0	1	1	0	0	0
October	0	0	0	0	0	0	0	0	0	0	224	0	0	0	23	0	0	58	16	0	1	0	174	253	0	1	1	0	0	0
November	0	0	0	0	0	0	0	0	0	0	223	0	0	0	41	0	0	95	51	0	1	0	119	209	0	1	1	0	0	0
December	0	0	0	0	0	0	0	0	0	0	204	0	0	0	61	0	0	66	38	0	1	0	160	246	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	211	0	0	0	33	0	0	58	36	0	1	0	150	252	0	1	1	0	Average price	
Maximum	0	0	0	0	0	0	0	0	0	0	348	0	1	0	97	0	0	184	86	0	1	0	313	332	0	65	65	0	(EUR/MWh)	
Minimum	0	0	0	0	0	0	0	0	0	0	92	0	0	0	7	0	0	0	0	0	1	0	0	100	0	0	0	0	58	55
TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.86	0.00	0.00	0.00	0.29	0.00	0.00	0.51	0.32	0.00	0.01	0.00	1.32		0.00	0.01	0.01	0.00	0	0

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Syntetic Fuel	Wind	Offsh.	Wave	Wave	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt) Total	Netto
Coal	-	-	-	-	-	0.85	-	-	-	-	-	-	-	-	-	-	-	-	0.17	0.12	1.14	0.00	1.14	0.41	0.40
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.27	1.39	1.01	6.68	0.00	6.68	1.75	1.75
N.Gas	-	-	-	-	-	1.95	-	-	-	-	-	-	-	-	-	-	-	-	1.04	0.70	3.68	-0.01	3.67	0.75	0.75
Biomass	-	-	-	-	-	-	-	-	-	-	0.16	-	-	-	-	-	-	-	0.04	0.17	0.37	0.00	0.37	0.00	0.00
Renewable	-	-	-	-	-	-	-	0.32	-	-	-	-	0.51	-	-	-	0.00	-	-	-	0.83	0.00	0.83	0.00	0.00
H2 etc.	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-0.11	-	-	-	-	-	-	0.11	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	2.80	-	0.32	-	-	0.05	-	0.51	-	-	-	0.00	4.39	2.64	2.00	12.70	-0.01	12.69	2.91	2.91

NEEAP/NREAP 2020

Input 1b. LCEP_NEEAP&NREAP_2020_Closed_30%.txt — **The EnergyPLAN model 10.0 Test**

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	1.79	Fixed imp/exp.	0.00
Electric heating	0.27	Transportation	0.03
Electric cooling	0.00	Total	2.09

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

Wind	330 MW	0.91	TWh/year	0.00	Grid
Offshore Wind	0 MW	0	TWh/year	0.00	stabili-
Wave Power	0 MW	0	TWh/year	0.00	sation
Tidal	0 MW	0	TWh/year	0.00	share
Hydro Power	86 MW	0.32	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	479		0.47		

Heatstorage: gr.2: 0 GWh gr.3: 0 GWh
Fixed Boiler: gr.2: 0.0 Per cent gr.3: 0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.01	0.00

Regulation Strate(Technical regulation no. 3

KEOL regulation	00000000	
Minimum Stabilisation share	0.30	
Stabilisation share of CHP	1.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0.50	
Maximum import/export	0	MW

GB_2020_market_price_900high.txt

Addition factor	0.00	EUR/MWh
Multiplication factor	1.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	59	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level:

	Capacities MW-e	Storage GWh	Efficie elec.	Th
Hydro Pump:	0	0	0.90	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biom
Transport	0.00	3.90	0.00	0.00
Household	0.15	0.98	0.69	0.13
Industry	0.12	0.79	0.68	0.38
Various	0.00	0.00	0.00	0.00

Output WARNING!!: (1) Critical Excess;

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Electricity / Exchange

	Consumption: Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange: Payment Imp (Million EUR)	Exp
January	205	3	1	0	52	0	0	120	81	0	1	0	82	197	0	22	22	0	0	1
February	210	3	1	0	48	0	0	73	61	0	1	0	129	237	0	1	1	0	0	0
March	206	4	1	0	38	0	0	123	63	0	1	0	86	189	0	24	24	0	0	1
April	190	4	1	0	33	0	0	92	12	0	1	0	134	205	0	10	10	0	0	0
May	194	3	1	0	24	0	0	106	10	0	1	0	126	190	0	21	21	0	0	1
June	200	3	0	0	14	0	0	60	13	0	1	0	147	240	0	3	3	0	0	0
July	201	4	0	0	12	0	0	88	38	0	1	0	103	208	0	12	12	0	0	1
August	202	3	0	0	12	0	0	109	37	0	1	0	87	181	0	17	17	0	0	1
September	207	3	0	0	17	0	0	79	18	0	1	0	140	223	0	11	11	0	0	0
October	215	4	1	0	21	0	0	104	16	0	1	0	146	210	0	25	25	0	0	1
November	215	3	1	0	38	0	0	170	51	0	1	0	80	148	0	44	44	0	0	2
December	198	4	1	0	57	0	0	119	38	0	1	0	122	194	0	21	21	0	0	1
Average	204	4	1	0	31	0	0	104	36	0	1	0	115	202	0	18	18	0	Average price	
Maximum	334	53	2	0	90	0	0	330	86	0	1	0	278	332	0	272	272	0	(EUR/MWh)	
Minimum	91	0	0	0	6	0	0	0	0	0	1	0	0	100	0	0	0	0	59	58
TWh/year	1.79	0.03	0.01	0.00	0.27	0.00	0.00	0.91	0.32	0.00	0.01	0.00	1.01		0.00	0.16	0.16	0.00	0	9

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Syntetic Fuel	Wind	Offsh.	Wave	Wave	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt) Total	Netto
Coal	-	-	-	-	-	0.65	-	-	-	-	-	-	-	-	-	-	-	-	0.16	0.12	0.92	-0.10	0.82	0.32	0.29
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.90	0.97	0.79	5.66	0.00	5.66	1.49	1.49
N.Gas	-	-	-	-	-	1.50	-	-	-	-	-	-	-	-	-	-	-	-	0.69	0.68	2.87	-0.23	2.64	0.59	0.54
Biomass	-	-	-	-	-	-	-	-	-	-	0.45	-	-	-	-	-	-	-	0.13	0.38	0.96	0.00	0.96	0.00	0.00
Renewable	-	-	-	-	-	-	-	0.32	-	-	-	-	0.91	-	-	-	0.01	-	-	-	1.24	0.00	1.24	0.00	0.00
H2 etc.	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-0.32	-	-	-	-	-	-	0.32	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	2.15	-	0.32	-	-	0.13	-	0.91	-	-	-	0.01	4.22	1.95	1.96	11.65	-0.33	11.32	2.40	2.32

DH&HP 2020

Input 2b. LCEP_RE_2020_Closed_30%_CHP&Boilers(Split).txt — The EnergyPLAN model 10.0 Test

Electricity demand (TWh/year): Flexible demand 0.00
Fixed demand 1.79 — Fixed imp/exp. 0.00
Electric heating 0.20 — Transportation 0.03
Electric cooling 0.00 — Total 2.02

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.13	0.07	0.20
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.13	0.07	0.20

Wind	330 MW	0.91	TWh/year	0.00	Grid
Photo Voltaic	0 MW	0	TWh/year	0.00	stabili-
Wave Power	0 MW	0	TWh/year	0.00	sation
Tidal	0 MW	0	TWh/year	0.00	share
Hydro Power	86 MW	0.32	TWh/year		
Geothermal/Nuclear	0 MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	40	30	0.52	0.39	
Heat Pump	0	0			3.00
Boiler		59		0.90	
Group 3:					
CHP	25	19	0.52	0.39	
Heat Pump	0	0			3.00
Boiler		30		0.90	
Condensing	473		0.47		

Heatstorage: gr.2: 3 GWh gr.32 GWh
Fixed Boiler: gr.2:1.0 Per cent gr.1.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.01	0.00

Regulation Strate(Technical regulation no. 3
KEOL regulation 00000000
Minimum Stabilisation share 0.30
Stabilisation share of CHP 1.00
Minimum CHP gr 3 load 0 MW
Minimum PP 0 MW
Heat Pump maximum share 0.50
Maximum import/export 0 MW

GB_2020_market_price_900high.txt
Addition factor 0.00 EUR/MWh
Multiplication factor 1.00
Dependency factor 0.00 EUR/MWh pr. MW
Average Market Price 59 EUR/MWh
Gas Storage 0 GWh
Syngas capacity 0 MW
Biogas max to grid 0 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficie elec.	Th
Hydro Pump:	0	0	0.90	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	

CAES fuel ratio: 0.000

(TWh/year)	Coal	Oil	Ngas	Bioma
Transport	0.00	3.90	0.00	0.00
Household	0.11	0.69	0.48	0.13
Industry	0.12	0.79	0.68	0.38
Various	0.00	0.00	0.00	0.00

Output WARNING!!: (1) Critical Excess;

District Heating

	Demand: Distr. heating MW	Production: Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW
January	37	0	0	0	32	0	0	6	0	0
February	34	0	0	0	35	0	0	1	0	-2
March	28	0	0	0	25	0	0	0	0	2
April	24	0	0	0	26	0	0	0	0	-2
May	18	0	0	0	17	0	0	0	0	1
June	12	0	0	0	12	0	0	0	0	0
July	10	0	0	0	10	0	0	0	0	0
August	10	0	0	0	10	0	0	0	0	0
September	14	0	0	0	14	0	0	0	0	0
October	17	0	0	0	18	0	0	0	0	-1
November	28	0	0	0	22	0	0	4	0	2
December	40	0	0	0	35	0	0	5	0	0
Average	23	0	0	0	21	0	0	1	0	0
Maximum	62	0	0	0	49	0	0	45	0	41
Minimum	7	0	0	0	0	0	0	0	0	-30
TWh/year	0.20	0.00	0.00	0.00	0.19	0.00	0.00	0.01	0.00	0.00

Electricity

	Consumption: Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW
January	209	3	15	0	39	0	0	120	81	0	1	42	42	198	0	19	19	0
February	214	3	14	0	36	0	0	73	61	0	1	47	85	238	0	0	0	0
March	208	4	11	0	29	0	0	123	63	0	1	33	53	189	0	22	22	0
April	191	4	10	0	25	0	0	91	12	0	1	34	99	204	0	8	8	0
May	193	3	7	0	18	0	0	106	10	0	1	23	101	189	0	20	20	0
June	197	3	4	0	11	0	0	60	13	0	1	16	128	238	0	2	2	0
July	197	4	4	0	9	0	0	88	38	0	1	13	86	206	0	12	12	0
August	198	3	3	0	9	0	0	109	37	0	1	14	70	178	0	17	17	0
September	204	3	5	0	13	0	0	79	18	0	1	18	119	222	0	11	11	0
October	213	4	6	0	16	0	0	103	16	0	1	23	121	210	0	25	25	0
November	216	4	11	0	29	0	0	170	51	0	1	29	50	148	0	42	42	0
December	203	4	16	0	42	0	0	119	38	0	1	47	79	195	0	19	19	0
Average	204	4	9	0	23	0	0	104	36	0	1	28	86	201	0	16	16	0
Maximum	327	53	26	0	67	0	0	330	86	0	1	65	239	332	0	273	273	0
Minimum	104	0	0	0	5	0	0	0	0	0	1	0	0	100	0	0	0	0
TWh/year	1.79	0.03	0.08	0.00	0.20	0.00	0.00	0.91	0.32	0.00	0.01	0.25	0.75		0.00	0.14	0.14	0.00

Exchange

	Payment Imp (Million EUR)	Payment Exp (Million EUR)
January	0	1
February	0	0
March	0	1
April	0	0
May	0	1
June	0	0
July	0	1
August	0	1
September	0	0
October	0	1
November	0	2
December	0	1
Average price (EUR/MWh)	59	58
TWh/year	0	8

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Syntetic Fuel	Wind	PV	Wave	Wave	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Netto	CO2 emission (Mt) Total	CO2 emission (Mt) Netto
Coal	-	-	-	-	-	0.48	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.12	0.71	-0.09	0.61	0.25	0.22
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.90	0.68	0.79	5.37	0.00	5.37	1.41	1.41
N.Gas	-	0.31	0.17	0.01	0.00	1.12	-	-	-	-	-	-	-	-	-	-	-	-	0.48	0.68	2.78	-0.22	2.56	0.57	0.52
Biomass	-	-	-	-	-	-	-	-	-	-	0.45	-	-	-	-	-	-	-	0.13	0.38	0.96	0.00	0.96	0.00	0.00
Renewable	-	-	-	-	-	-	-	0.32	-	-	-	-	0.91	-	-	-	0.01	-	-	-	1.24	0.00	1.24	0.00	0.00
H2 etc.	-	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-0.32	-	-	-	-	-	-	0.32	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	0.31	0.17	0.01	0.00	1.61	-	0.32	-	-	0.13	-	0.91	-	-	-	0.01	4.22	1.41	1.96	11.05	-0.31	10.75	2.23	2.15

LCR 2020 (DH&HP+RE)

Input 3b. LCEP_RE_2020_Closed_30%_CHP&Boilers&HP&Solar(Split).txt The EnergyPLAN model 10.0 Test

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	1.79	Fixed imp/exp.	0.00
Electric heating	0.20	Transportation	0.03
Electric cooling	0.00	Total	2.02

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.13	0.07	0.20
Solar Thermal	0.00	0.01	0.01	0.02
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.12	0.06	0.18

Wind	330	MW	0.91	TWh/year	0.00	Grid
Photo Voltaic	25	MW	0.03	TWh/year	0.00	stabili-
Wave Power	0	MW	0	TWh/year	0.00	sation
Tidal	10	MW	0.04	TWh/year	0.00	share
Hydro Power	86	MW	0.32	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	40	30	0.52	0.39	
Heat Pump	4	11			3.00
Boiler		59		0.90	
Group 3:					
CHP	25	19	0.52	0.39	
Heat Pump	2	5			3.00
Boiler		30		0.90	
Condensing	478		0.47		

Heatstorage: gr.2: 3 GWh gr.3: 2 GWh
Fixed Boiler: gr.2: 1.0 Per cent gr.3: 1.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.01	0.00

Regulation Strategy:	Technical regulation no. 3	
KEOL regulation	00000000	
Minimum Stabilisation share	0.30	
Stabilisation share of CHP	1.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0.50	
Maximum import/export	0	MW

DiGB_2020_market_price_900high.txt

Addition factor	0.00	EUR/MWh
Multiplication factor	1.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	59	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	51	MW

Fuel Price level:

	Capacities	Storage	Efficiencies	
	MW-e	GWh	elec.	Ther.
Hydro Pump:	0	0	0.90	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	3.90	0.00	0.00
Household	0.11	0.73	0.53	0.13
Industry	0.12	0.79	0.68	0.38
Various	0.00	0.00	0.00	0.00

Output WARNING!!: (1) Critical Excess;

	District Heating: Demand	Production								Ba-	Electricity Consumption						Production							Balance						Exchange Payment	
	Distr. heating MW	Solar MW	Waste+ CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	lance MW	Elec. demand MW	Flex.& Transp. MW	HP MW	Elec- trolyser MW	EH MW	Hydro Pump MW	Tur- bine MW	RES MW	Hy- dro MW	Geo- thermal MW	Waste+ CSHP MW	CHP MW	PP MW	Stab- Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Imp Million EUR	Exp Million EUR
January	37	0	0	0	29	6	0	1	0	0	209	3	17	0	39	0	0	125	81	0	1	39	43	194	0	20	20	0	0	1
February	34	1	0	0	32	1	0	0	0	-1	214	3	14	0	36	0	0	78	61	0	1	43	84	231	0	1	1	0	0	0
March	28	2	0	0	19	5	0	0	0	1	208	4	13	0	29	0	0	130	63	0	1	26	56	182	0	23	23	0	0	1
April	24	3	0	0	19	2	0	0	0	0	191	4	10	0	25	0	0	100	12	0	1	25	101	194	0	9	9	0	0	0
May	18	4	0	0	12	3	0	0	0	0	193	3	8	0	18	0	0	115	10	0	1	16	102	179	0	22	22	0	0	1
June	12	3	0	0	8	0	0	0	0	0	197	3	4	0	11	0	0	69	13	0	1	11	124	226	0	2	2	0	0	0
July	10	3	0	0	6	1	0	0	0	0	197	4	4	0	9	0	0	98	38	0	1	8	84	195	0	14	14	0	0	1
August	10	3	0	0	5	2	0	0	0	0	198	3	4	0	9	0	0	118	37	0	1	7	72	170	0	20	20	0	0	1
September	14	2	0	0	10	1	0	0	0	0	204	3	5	0	13	0	0	87	18	0	1	14	119	214	0	13	13	0	0	1
October	17	1	0	0	13	3	0	0	0	-1	213	4	7	0	16	0	0	109	16	0	1	17	124	204	0	26	26	0	0	1
November	28	1	0	0	18	8	0	0	0	1	216	4	14	0	29	0	0	175	51	0	1	24	54	145	0	44	44	0	0	2
December	40	0	0	0	33	5	0	2	0	0	203	4	18	0	42	0	0	124	38	0	1	43	80	191	0	19	19	0	0	1
Average	23	2	0	0	17	3	0	0	0	0	204	4	10	0	23	0	0	111	36	0	1	23	87	193	0	18	18	0	Average price	
Maximum	62	10	0	0	49	15	0	30	0	28	327	53	31	0	67	0	0	346	86	0	1	65	243	327	0	276	276	0	(EUR/MWh)	
Minimum	7	0	0	0	0	0	0	0	0	-23	104	0	0	0	5	0	0	3	0	0	1	0	0	100	0	0	0	0	59	58
TWh/year	0.20	0.02	0.00	0.00	0.15	0.03	0.00	0.00	0.00	0.00	1.79	0.03	0.09	0.00	0.20	0.00	0.00	0.97	0.32	0.00	0.01	0.20	0.76		0.00	0.16	0.16	0.00	0	9

FUEL BALANCE (TWh/year):	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon- version	Syntetic Fuel	Wind	PV	Wave	Wave	Solar.Th.	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Netto	CO2 emission (Mt): Total	CO2 emission (Mt): Netto
Coal	-	-	-	-	-	0.49	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.12	0.71	-0.10	0.61	0.25	0.22
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.90	0.67	0.79	5.36	0.00	5.36	1.41	1.41
N.Gas	-	0.25	0.13	0.00	0.00	1.13	-	-	-	-	-0.45	-	-	-	-	-	-	-	0.48	0.68	2.23	-0.23	2.00	0.46	0.41
Biomass	-	-	-	-	-	-	-	-	-	-	0.91	-	-	-	-	-	-	-	0.13	0.38	1.42	0.00	1.42	0.00	0.00
Renewable	-	-	-	-	-	-	-	0.32	-	-	-	-	0.91	0.03	-	0.04	0.11	-	-	-	1.41	0.00	1.41	0.00	0.00
H2 etc.	-	0.00	0.00	0.00	0.00	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-0.32	-	-	-	-	-	-	0.32	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	0.25	0.13	0.00	0.00	1.62	-	0.32	-	-	0.14	-	0.91	0.03	-	0.04	0.11	4.22	1.39	1.96	11.13	-0.33	10.80	2.12	2.03

NEEAP/NREAP 2050

Input 0b. LCEP_NEEAP&NREAP_2050_REF_Closed_0%.txt — The EnergyPLAN model 10.0 Test

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	2.38	Fixed imp/exp.	0.00
Electric heating	0.21	Transportation	0.13
Electric cooling	0.00	Total	2.71

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

Wind	490	MW	1.35	TWh/year	0.00	Grid
Photo Voltaic	0	MW	0	TWh/year	0.00	stabili-
Wave Power	0	MW	0	TWh/year	0.00	sation
Tidal	0	MW	0	TWh/year	0.00	share
Hydro Power	86	MW	0.32	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	436		0.57		

Heatstorage: gr.2: 0 GWh gr.30 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.01	0.00

Regulation Strate(	Technical regulation no. 3	
KEOL regulation	23450000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	0.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0.50	
Maximum import/export	0	MW

GB_2020_market_price_900high.txt

Addition factor	0.00	EUR/MWh
Multiplication factor	1.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	59	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	0	MW
Biogas max to grid	0	MW

Fuel Price level: Basic

	Capacities	Storage	Efficie[ncies]	
	MW-e	GWh	elec.	Th[er]
Hydro Pump:	0	0	0.90	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	0	0	0.80	0.10
Electrol. trans.:	0	0	0.80	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biom[ass]
Transport	0.00	4.64	0.00	0.00
Household	0.00	0.47	0.62	0.39
Industry	0.11	0.55	1.12	0.97
Various	0.00	0.00	0.00	0.00

Output WARNING!!: (1) Critical Excess;

	District Heating: Demand	Production								Balance	Electricity: Consumption						Production							Balance					Exchange	
	Distr. heating MW	Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Payment Imp Million EUR	Exp
January	0	0	0	0	0	0	0	0	0	0	284	13	4	0	40	0	0	178	81	0	1	0	100	100	0	18	18	0	0	1
February	0	0	0	0	0	0	0	0	0	0	288	13	4	0	36	0	0	108	61	0	1	0	172	100	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0	278	14	3	0	30	0	0	182	63	0	1	0	96	100	0	17	17	0	0	1
April	0	0	0	0	0	0	0	0	0	0	255	15	3	0	26	0	0	136	12	0	1	0	150	100	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0	256	14	2	0	19	0	0	158	10	0	1	0	130	100	0	8	8	0	0	0
June	0	0	0	0	0	0	0	0	0	0	258	14	1	0	12	0	0	89	13	0	1	0	183	100	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0	257	16	1	0	11	0	0	131	38	0	1	0	121	100	0	4	4	0	0	0
August	0	0	0	0	0	0	0	0	0	0	259	13	1	0	10	0	0	162	37	0	1	0	89	100	0	5	5	0	0	0
September	0	0	0	0	0	0	0	0	0	0	268	14	1	0	14	0	0	118	18	0	1	0	162	100	0	2	2	0	0	0
October	0	0	0	0	0	0	0	0	0	0	281	16	2	0	17	0	0	154	16	0	1	0	153	100	0	8	8	0	0	0
November	0	0	0	0	0	0	0	0	0	0	289	15	3	0	30	0	0	252	51	0	1	0	63	100	0	31	31	0	0	1
December	0	0	0	0	0	0	0	0	0	0	277	15	4	0	43	0	0	177	38	0	1	0	132	100	0	9	9	0	0	0
Average	0	0	0	0	0	0	0	0	0	0	271	14	3	0	24	0	0	154	36	0	1	0	129	100	0	9	9	0	Average price	
Maximum	0	0	0	0	0	0	0	0	0	0	428	212	7	0	67	0	0	490	86	0	1	0	369	100	0	291	291	0	(EUR/MWh)	
Minimum	0	0	0	0	0	0	0	0	0	0	150	0	0	0	7	0	0	0	0	0	1	0	0	100	0	0	0	0	59	59
TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.38	0.13	0.02	0.00	0.21	0.00	0.00	1.35	0.32	0.00	0.01	0.00	1.13		0.00	0.08	0.08	0.00	0	4

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Syntetic Fuel	Wind	PV	Wave	Wave	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt) Total	Netto
Coal	-	-	-	-	-	0.42	-	-	-	-	-	-	-	-	-	-	-	-	-	0.11	0.53	-0.03	0.50	0.19	0.18
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	4.64	0.46	0.55	5.65	0.00	5.65	1.48	1.48
N.Gas	-	-	-	-	-	1.55	-	-	-	-	-	-	-	-	-	-	-	-	0.61	1.12	3.29	-0.10	3.18	0.67	0.65
Biomass	-	-	-	-	-	-	-	-	-	-	1.49	-	-	-	-	-	-	-	0.39	0.97	2.84	0.00	2.84	0.00	0.00
Renewable	-	-	-	-	-	-	-	0.32	-	-	-	-	1.35	-	-	-	0.02	-	-	-	1.69	0.00	1.69	0.00	0.00
H2 etc.	-	-	-	-	-	0.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-1.06	-	-	-	-	-	-	1.06	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	1.97	-	0.32	-	-	0.42	-	1.35	-	-	-	0.02	5.70	1.46	2.75	14.00	-0.13	13.87	2.34	2.31

LCR 2050 (DH&HP+H2)

Input 6. LCEP_NEEAP&NREAP_2050_HP_Closed_0%_H2.txt — The EnergyPLAN model 10.0 Test

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	2.41	Fixed imp/exp.	0.00
Electric heating	0.07	Transportation	0.47
Electric cooling	0.00	Total	2.95

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.00	0.00
Solar Thermal	0.00	0.00	0.00	0.00
Industrial CHP (CSHP)	0.00	0.00	0.00	0.00
Demand after solar and CSHP	0.00	0.00	0.00	0.00

Wind	1340	MW	3.70	TWh/year	0.00	Grid
Photo Voltaic	250	MW	0.26	TWh/year	0.00	stabili-
Wave Power	250	MW	0.68	TWh/year	0.00	sation
Tidal	30	MW	0.11	TWh/year	0.00	share
Hydro Power	86	MW	0.32	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities		Efficiencies		
Group 2:	MW-e	MJ/s	elec.	Ther	COP
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Group 3:					
CHP	0	0	0.40	0.50	
Heat Pump	0	0			3.00
Boiler		0		0.90	
Condensing	820		0.61		

Heatstorage: gr.2: 0 GWh gr.30 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.0.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.01	0.00

Regulation Strategy: Technical regulation no. 3		
KEOL regulation	23450000	
Minimum Stabilisation share	0.00	
Stabilisation share of CHP	1.00	
Minimum CHP gr 3 load	0	MW
Minimum PP	0	MW
Heat Pump maximum share	0.50	
Maximum import/export	0	MW

GB_2020_market_price_900high.txt		
Addition factor	0.00	EUR/MWh
Multiplication factor	1.00	
Dependency factor	0.00	EUR/MWh pr. MW
Average Market Price	59	EUR/MWh
Gas Storage	0	GWh
Syngas capacity	364	MW
Biogas max to grid	105	MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Ther
Hydro Pump:	0	0	0.90	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.80	0.10
Electrol. Gr.3:	300	14	0.73	0.10
Electrol. trans.:	302	14	0.73	
Ely. MicroCHP:	0	0	0.80	
CAES fuel ratio:	0.000			

(TWh/year)	Coal	Oil	Ngas	Biomass
Transport	0.00	0.00	2.71	0.00
Household	0.00	0.00	0.00	0.11
Industry	0.00	0.00	0.00	2.75
Various	0.00	0.00	0.00	0.00

Output WARNING!!: (1) Critical Excess;

District Heating (MW):

	Demand: Distr. heating	Solar	Waste-CSHP	DHP	CHP	HP	ELT	Boiler	EH	Ba-lance
January	0	0	0	0	0	0	0	0	0	0
February	0	0	0	0	0	0	0	0	0	0
March	0	0	0	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0
May	0	0	0	0	0	0	0	0	0	0
June	0	0	0	0	0	0	0	0	0	0
July	0	0	0	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0	0	0	0
October	0	0	0	0	0	0	0	0	0	0
November	0	0	0	0	0	0	0	0	0	0
December	0	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0	0
Minimum	0	0	0	0	0	0	0	0	0	0
TWh/year	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Electricity (MW) and Exchange:

	Elec. demand	Flex.& Transp	HP	Elec-trolyser	EH	Hydro Pump	Tur-bine	RES	Hy-dro	Geo-thermal	Waste-CSHP	CHP	PP	Stab-Load %	Imp	Exp	CEEP	EEP	Payment Imp (Million EUR)	Exp
January	296	51	65	352	14	0	0	647	81	0	1	0	84	100	0	34	34	0	0	2
February	298	52	60	232	13	0	0	444	61	0	1	0	150	100	0	0	0	0	0	0
March	285	54	46	357	11	0	0	642	63	0	1	0	76	100	0	30	30	0	0	1
April	260	53	40	263	9	0	0	462	12	0	1	0	151	100	0	0	0	0	0	0
May	257	53	27	307	7	0	0	552	10	0	1	0	104	100	0	16	16	0	0	1
June	255	53	17	241	4	0	0	337	13	0	1	0	221	100	0	0	0	0	0	0
July	254	56	14	303	4	0	0	461	38	0	1	0	138	100	0	6	6	0	0	0
August	255	50	14	341	4	0	0	542	37	0	1	0	86	100	0	1	1	0	0	0
September	266	53	20	258	5	0	0	428	18	0	1	0	164	100	0	9	9	0	0	0
October	280	54	29	331	6	0	0	526	16	0	1	0	177	100	0	19	19	0	0	1
November	295	55	49	413	11	0	0	795	51	0	1	0	44	100	0	69	69	0	0	3
December	291	55	71	323	15	0	0	644	38	0	1	0	100	100	0	28	28	0	0	1
Average	274	53	38	311	9	0	0	541	36	0	1	0	124	100	0	18	18	0	Average price	
Maximum	424	379	112	602	24	0	0	1513	86	0	1	0	604	100	0	721	721	0	(EUR/MWh)	
Minimum	156	0	0	55	2	0	0	30	0	0	1	0	0	100	0	0	0	0	58	58
TWh/year	2.41	0.47	0.33	2.73	0.08	0.00	0.00	4.75	0.32	0.00	0.01	0.00	1.09		0.00	0.16	0.16	0.00	0	9

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Syntetic Fuel	Wind	PV	Wave	Wave	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Netto	CO2 emission (Mt) Total	Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
N.Gas	-	-	-	-	-	1.40	-	-	-	-	-4.11	-	-	-	-	-	-	2.71	-	-	0.00	-0.25	-0.25	0.00	-0.05
Biomass	-	-	-	-	-	-	-	-	-	-	4.88	-	-	-	-	-	-	-	0.11	2.75	7.74	0.00	7.74	0.00	0.00
Renewable	-	-	-	-	-	-	-	0.32	-	-	-	-	3.70	0.26	0.68	0.11	0.08	-	-	-	5.15	0.00	5.15	0.00	0.00
H2 etc.	-	-	-	-	-	0.37	-	-	-	-1.99	-	-	-	-	-	-	-	1.49	-	-	-0.13	0.00	-0.13	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	-	-	-	1.77	-	0.32	-	-1.99	0.77	-	3.70	0.26	0.68	0.11	0.08	4.20	0.11	2.75	12.75	-0.25	12.50	0.00	-0.05

HP&H2 2050

Input H. LCEP_NEEAP_2050_DH&CHP_Closed_0%_HP_Sol_Ind_BiThe EnergyPLAN model 10.0 Test

Electricity demand (TWh/year):		Flexible demand	0.00
Fixed demand	2.41	Fixed imp/exp.	0.00
Electric heating	0.07	Transportation	0.47
Electric cooling	0.00	Total	2.95

District heating (TWh/year)	Gr.1	Gr.2	Gr.3	Sum
District heating demand	0.00	0.00	0.80	0.80
Solar Thermal	0.00	0.00	0.12	0.12
Industrial CHP (CSHP)	0.00	0.00	0.27	0.27
Demand after solar and CSHP	0.00	0.00	0.41	0.41

Wind	1280	MW	3.53	TWh/year	0.00	Grid
Photo Voltaic	250	MW	0.26	TWh/year	0.00	stabili-
Wave Power	250	MW	0.68	TWh/year	0.00	sation
Tidal	30	MW	0.11	TWh/year	0.00	share
Hydro Power	86	MW	0.32	TWh/year		
Geothermal/Nuclear	0	MW	0	TWh/year		

	Capacities MW-e	Capacities MJ/s	Efficiencies elec.	Efficiencies Ther	COP
Group 2:					
CHP	0	0	0.46	0.51	
Heat Pump	0	0			4.00
Boiler		0		0.90	
Group 3:					
CHP	20	15	0.52	0.39	
Heat Pump	20	80			4.00
Boiler		311		0.90	
Condensing	744		0.61		

Heatstorage: gr.2: 0 GWh gr.18 GWh
Fixed Boiler: gr.2:0.0 Per cent gr.1.0 Per cent

Electricity prod. from	CSHP	Waste (TWh/year)
Gr.1:	0.00	0.00
Gr.2:	0.00	0.00
Gr.3:	0.01	0.00

Regulation Strateg Technical regulation no. 3
KEOL regulation 23000000
Minimum Stabilisation share 0.00
Stabilisation share of CHP 1.00
Minimum CHP gr 3 load 0 MW
Minimum PP 0 MW
Heat Pump maximum share 0.50
Maximum import/export 0 MW

GB_2020_market_price_900high.txt
Addition factor 0.00 EUR/MWh
Multiplication factor 1.00
Dependency factor 0.00 EUR/MWh pr. MW
Average Market Price 59 EUR/MWh
Gas Storage 0 GWh
Syngas capacity 364 MW
Biogas max to grid 105 MW

Fuel Price level: Basic

	Capacities MW-e	Storage GWh	Efficiencies elec.	Th
Hydro Pump:	0	0	0.90	
Hydro Turbine:	0		0.90	
Electrol. Gr.2:	0	0	0.73	0.10
Electrol. Gr.3:	300	14	0.73	0.10
Electrol. trans.:	302	14	0.73	
Ely. MicroCHP:	0	0	0.80	

CAES fuel ratio: 0.000

(TWh/year)	Coal	Oil	Ngas	Bioms
Transport	0.00	0.00	2.71	0.00
Household	0.00	0.00	0.00	0.11
Industry	0.00	0.00	0.00	2.75
Various	0.00	0.00	0.00	0.00

Output WARNING!!: (1) Critical Excess;

	District Heating: Demand Distr. heating MW	Production Solar MW	Waste-CSHP MW	DHP MW	CHP MW	HP MW	ELT MW	Boiler MW	EH MW	Ba-lance MW	Electricity Consumption: Elec. demand MW	Flex.& Transp MW	HP MW	Elec-trolyser MW	EH MW	Hydro Pump MW	Production: Tur-bine MW	RES MW	Hy-dro MW	Geo-thermal MW	Waste-CSHP MW	CHP MW	PP MW	Balance: Stab-Load %	Imp MW	Exp MW	CEEP MW	EEP MW	Exchange Payment Imp (Million EUR)	Exp (Million EUR)
January	146	3	96	0	6	39	0	0	0	0	296	51	44	353	14	0	0	625	81	0	1	9	73	100	0	31	31	0	0	1
February	134	7	92	0	10	26	0	0	0	0	298	52	37	236	13	0	0	431	61	0	1	13	131	100	0	0	0	0	0	0
March	110	12	83	0	5	14	0	0	0	-4	285	54	26	359	11	0	0	620	63	0	1	6	71	100	0	26	26	0	0	1
April	97	22	78	0	5	4	0	0	0	-12	260	53	20	265	9	0	0	445	12	0	1	6	143	100	0	0	0	0	0	0
May	76	24	71	0	1	2	0	0	0	-22	257	53	13	307	7	0	0	533	10	0	1	1	105	100	0	13	13	0	0	1
June	51	23	62	0	0	1	0	0	0	-34	255	53	7	241	4	0	0	326	13	0	0	0	221	100	0	0	0	0	0	0
July	45	22	60	0	0	1	0	0	0	-37	254	56	6	301	4	0	0	444	38	0	0	0	141	100	0	4	4	0	0	0
August	44	22	59	0	0	1	0	0	0	-37	255	51	6	336	4	0	0	522	37	0	0	0	92	100	0	0	0	0	0	0
September	58	14	64	0	0	1	0	0	0	-22	266	53	10	257	5	0	0	413	18	0	1	0	164	100	0	6	6	0	0	0
October	69	8	68	0	2	2	0	0	0	-10	280	54	15	330	6	0	0	507	16	0	1	2	174	100	0	15	15	0	0	1
November	111	4	83	0	3	21	1	0	0	-1	295	55	30	412	11	0	0	764	51	0	1	4	42	100	0	60	60	0	0	3
December	157	2	100	0	7	46	0	0	0	0	291	54	48	326	15	0	0	622	38	0	2	10	88	100	0	25	25	0	0	1
Average	91	14	76	0	3	13	0	0	0	-15	274	53	22	311	9	0	0	522	36	0	1	4	120	100	0	15	15	0	Average price	
Maximum	239	63	130	0	15	80	3	14	0	4	424	379	78	602	24	0	0	1454	86	0	2	20	578	100	0	678	678	0	(EUR/MWh)	
Minimum	31	0	54	0	0	1	0	0	0	-39	156	0	0	55	2	0	0	29	0	0	0	0	0	100	0	0	0	0	59	59
TWh/year	0.80	0.12	0.67	0.00	0.03	0.12	0.00	0.00	0.00	-0.13	2.41	0.47	0.19	2.73	0.08	0.00	0.00	4.58	0.32	0.00	0.01	0.04	1.06		0.00	0.13	0.13	0.00	0	8

FUEL BALANCE (TWh/year):

	DHP	CHP2	CHP3	Boiler2	Boiler3	PP	Geo/Nu.	Hydro	Waste	CAES Elc.ly.	BioCon-version	Syntetic Fuel	Wind	PV	Wave	Wave	Solar.Th	Transp.	househ.	Industry Various	Total	Imp/Exp Corrected Imp/Exp	Imp/Exp Corrected Netto	CO2 emission (Mt) Total	CO2 emission (Mt) Netto
Coal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Oil	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
N.Gas	-	-	0.05	-	0.00	1.36	-	-	-	-	-4.12	-	-	-	-	-	-	2.71	-	-	0.00	-0.22	-0.22	0.00	-0.04
Biomass	-	-	-	-	-	-	-	-	-	-	4.89	-	-	-	-	-	-	-	0.11	2.75	7.75	0.00	7.75	0.00	0.00
Renewable	-	-	-	-	-	-	-	0.32	-	-	-	-	3.53	0.26	0.68	0.11	0.20	-	-	-	5.10	0.00	5.10	0.00	0.00
H2 etc.	-	-	0.03	-	0.00	0.35	-	-	-	-1.99	-	-	-	-	-	-	-	1.49	-	-	-0.12	0.00	-0.12	0.00	0.00
Biofuel	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Nuclear	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.00	0.00	0.00	0.00	0.00
Total	-	-	0.07	-	0.00	1.72	-	0.32	-	-1.99	0.77	-	3.53	0.26	0.68	0.11	0.20	4.20	0.11	2.75	12.73	-0.22	12.51	0.00	-0.04

Appendix VIII.Renewable Energy Resource Assessment of County Clare and County Limerick

Renewable Energy Resource Assessment of County Clare and County Limerick

LIMERICK CLARE
energy agency

June 2012

Client:

Crystal Energy on behalf of the Limerick Clare Energy Agency

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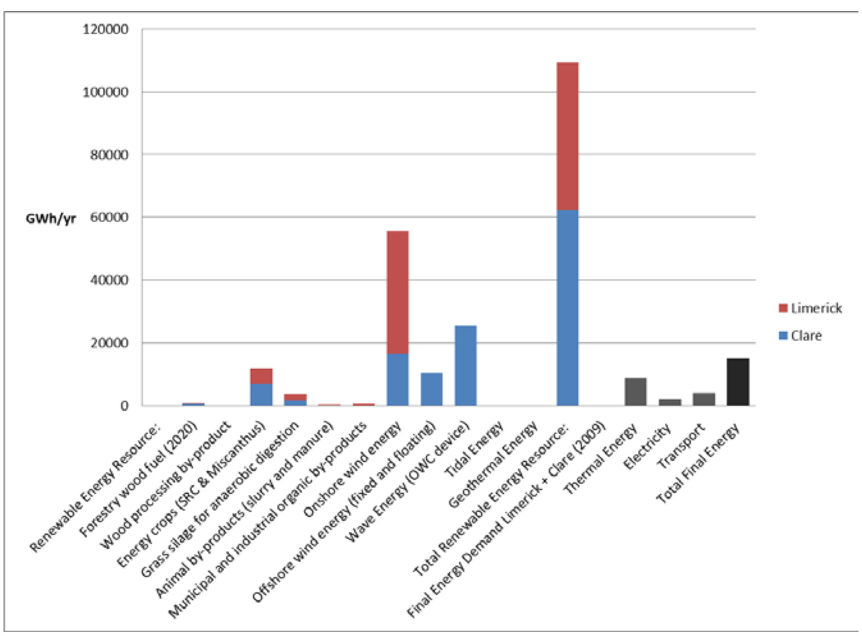
Executive Summary

The objective of this part of the study is to assess the potential renewable energy resource available within County Limerick and County Clare. This analysis draws primarily on published data from national agencies and regional organisations. The methodology applied in the analysis was primarily developed from the experience and models created in the framework of study 'A Renewable Energy Roadmap for the Clonakilty District' undertaken by Sustainable Clonakilty (West Cork).

The total theoretical potential for wind, wave and bioenergy in the study area was estimated at 109 TWh of renewable energy resource. This is over six times the final energy demand of the region. The bulk of that resource lies with on-shore and offshore wind energy as well as wave energy, which together can potentially generate an amount of electricity equivalent to over 6 times the total final energy demand. The theoretical potential of bioenergy in the study area has been estimated at 17,680 GWh or 117% of the final energy consumption in the area. The potential consists primarily in woody biomass from forestry and energy crops (72% of total biomass) and the remaining bioenergy resource consists in wet materials such as grass silage and organic waste suitable for anaerobic digestion. The results are summarised in the graph below:



It must be noted that the estimates obtained from this analysis are theoretical in that in many cases they haven't been constrained by economic, environmental or socio-cultural considerations. This will serve as a basis to determine the nature of the renewable energy systems designed to fulfil the energy demand of the region in the subsequent steps of the overall study.

Contents

1 Introduction

The objective of this part of the study is to assess the potential renewable energy resource available within County Limerick and County Clare. Renewable energy is derived from natural phenomena such as sunlight, wind, tides, plant growth, and geothermal heat, which are replenished constantly.

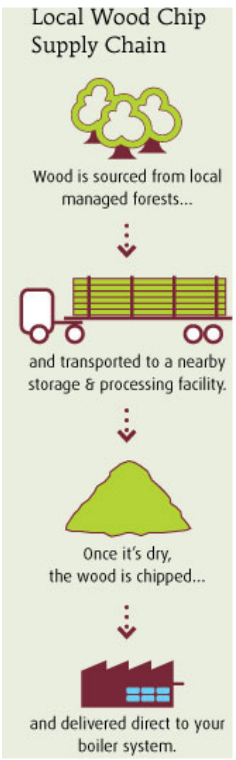
Where the renewable energy resource is available as a primary fuel in liquid, solid or gaseous form, our assessment will quantify the estimated resource on the basis of its energy content. This will be the case for the bioenergy resources assessed e.g. wood fuel, biogas, etc. For resources such as wind, solar, tidal and other forms of renewable energy which are converted directly into final energy, we will quantify the estimated resource in the form of potential thermal or electrical output from the relevant energy systems e.g. wind turbines, solar photovoltaic panels, etc.

This analysis drew primarily on published data from national agencies (Central Statistics Office, SEAI, Environmental Protection Agency, etc.) and regional organisations (Limerick Clare Energy Agency, Western Development Commission, Clare Local Development Company, etc.). The methodology applied in the analysis also draws from the experience and models developed in the framework of study 'A Renewable Energy Roadmap for the Clonakilty District' undertaken by Sustainable Clonakilty and funded by the West Cork Development Partnership (Dubuisson, Stuart, & Kupova, 2011).

2 Biomass

Biomass is a very broad term which is used to describe material of recent biological origin that can be used either as a source of energy or for its chemical components. As such, it includes trees, crops, algae and other plants, as well as agricultural and forest residues. It also includes many materials that are considered as wastes by our society including food and drink manufacturing effluents, sludges, manures, industrial (organic) by-products and the organic fraction of household waste. In many ways biomass can be considered as a form of stored solar energy. The energy of the sun is 'captured' through the process of photosynthesis in growing plants. The term 'bioenergy' is used for biomass energy systems that produce heat and/or electricity and 'biofuels' for liquid fuels for transportation. The following website of the International Energy Agency provides a wealth of information on bioenergy: http://www.aboutbioenergy.info/index.html

2.1 Forestry



Wood fuel produced by the forestry sector at different stages of the lifecycle of a forest probably represents the largest bioenergy resource available in the study area. Thinning and felling by-products which have no wood processing outlet (construction timber, boards, etc.) are an ideal source for wood fuel production, typically as logs or chips. The County Clare Wood Energy Project is a practical demonstration of the successful establishment of a wood fuel supply chain to valorise this resource locally, see http://www.ccwep.ie/default.asp for details.

Forestry thinning in the small diameter assortment (7-13 mm, generally referred to as pulpwood or stakewood) represents the main potential for wood energy purposes. A certain amount of the larger diameter assortment (14-19 mm, also referred to as pallet wood) could become available as downgrade material or in areas where transport cost becomes prohibitive to bring it to relevant wood processing centres. Additional raw material is potentially available through the harvesting of tree tips (tip–7 cm) and through the collection of harvesting residues and some harvest loss material) on suitable sites.

2.1.1 Assessment of the energy potential from forestry

The forecast of potential net realisable volume forestry production for Clare and Limerick was taken from Coford's report *'All Ireland Roundwood Production Forecast 2011-2028'* (Philips, 2011). – this is considered as the theoretical (unconstrained) potential (see Table 1). This represents a total amount of roundwood produced in the region of circa 500 thousand m3/yr in 2020 and 600 thousand m3/yr by 2030; this is approximately 10% of the whole-island production. If all this was used for energy purposes, this would represent a primary wood fuel resource for the region of 947 and 1157 GWhr by 2020 and 2030 respectively (equivalent to 6 and 8% of the total final energy consumption).

Table 1 Estimate of the total wood fibre potential

Estimate of Wood Fibre Potential	Theoretical Potential		
Clare	2011	2020	2028
Tip-7 cm cm assortment (,000 m3/yr)	7	13	8
7-13 cm assortment (,000 m3/yr)	48	88	55
14-19 cm assortment (,000 m3/yr)	68	128	116
20+ assortment (,000 m3/yr)	83	145	227
Total available for energy (,000 m3)	206	374	406
Total forestry energy resource (GWh) (*)	***395.1***	***717.2***	***778.6***
Limerick	2011	2020	2028
Tip-7 cm cm assortment (,000 m3/yr)	3	5	5
7-13 cm assortment (,000 m3/yr)	28	42	30
14-19 cm assortment (,000 m3/yr) (*)	38	43	56
20+ assortment (,000 m3/yr) (**)	47	35	101
Total available for energy (,000 m3)	116	125	192
Total forestry energy resource (GWh) (*)	***222.5***	***239.7***	***368.2***
Total study area (GWh/yr)	617.5	956.9	1146.8
% of total demand	4.1%	6.3%	7.6%

(*) A conversion factor of 6.9 GJ/m3 of round wood was used (Philips, 2011).

The theoretical potential for wood energy from forestry activities is estimated at 368 GWh by 2030, or c.8% of the final energy consumption in the study area. It should be emphasized that this renewable energy resource estimate doesn't consider competing uses of roundwood for construction timber, wood stakes, pallets, etc. This should be compared with Coford's estimate (Philips, 2011) of the total wood fibre available for energy at a national level of 1.45 million m3 which can be apportioned to 165,000 m3 for the study area[1].

2.2 Wood processing by-products

Finsa Forest is the only significant wood processing plant in the region, located in Scariff in County Clare. Finsa buys approximately 350,000 tonnes of timber per year and it is assumed that the factory could become a net source of wood fuel (e.g. sawdust) for the region (Tom Bruton, 2008). The effect of Finsa's demand for wood products on the wood fibre availability for energy in the study area has not been measured.

[1] This estimate is comparable to the results presented in the RAL-RES project report on the wood fuel resource in the region under the remit of the Western Development Commission (T. Bruton et al, 2010).

2.3 Energy Crops

Biomass fuels produced from purpose grown agricultural crops such as sugar beet, straw and fast growing willow coppice (CCEP, 2011). Commercial energy crops are typically densely planted, high yielding crop species cultivated to produce liquid fuels (biofuels from corn, oil seed rape, etc.), solid fuels (short rotation coppice (SRC), Miscanthus, etc.) or biogas (maize or grass silage).

2.3.1 Miscanthus

Miscanthus is a high-yielding perennial, rhizomatous grass with lignified stems resembling bamboo. Once established (typically requires 2-3 years) miscanthus can remain in situ for at least fifteen years. Miscanthus is planted in spring and harvested over the winter and early spring months. The crop is growing throughout the country on a wide range of soils, from sands to high organic matter soils. Harvestable yields vary on average between 12 and 16 t/ha,year.

Figure 1: 2 year old miscanthus plantation in Ballinspittle, West Cork, with owner Brian Hayes (Source: XD Consulting).

According to SEAI's Bioenergy Maps, there are currently 303 ha of Miscanthus planted in Co. Limerick and (maps.seai.ie/bioenergy/) and only 6 ha in County Clare. There are a total of 3000 ha planted with Miscanthus in the Republic of Ireland. The main markets for Miscanthus crops include co-firing in the Edenderry peat power plant (120 tonnes in 2009 according to J. Reilly (2010)) combustion in commercial or domestic heating appliances (as chips, briquettes and pellets) or combined heat and power (CHP).

2.3.2 Short Rotation Coppice (SRC)

The crop is capable of yielding 10 to 12 oven-dry tonnes of biomass per hectare per annum on good sites, but it is expected that new clones will yield 12-14 OD tonnes/ha,year (B CASLIN, 2010). 370 ha have been planted under the Bioenergy Scheme. The application of wastewater or wastewater treatment sludge to a short rotation coppice stand can increase average yields by up to 30%, by increasing the availability of nutrients and water to the plantation – two growth factors to which willow responds very well. This is referred to as biofiltration or bioremediation. It has attracted a lot of attention in recent years as an effective system to treat wastewater and other effluents, which provides additional income to growers through gate fees and increase yields.

2.3.3 Grass silage

Silage is forage biomass harvested and fermented for use as winter fodder for cattle and sheep. Grass silage is harvested in the summer and stored anaerobically in a silage clamp under plastic sheeting, or in a silo. Although silage is primarily produced as a feed, excess production can also be suitable as a biomass. Moisture content is high, typically 60-75%, and so it is not efficient to burn it, however it may be used as feedstock for anaerobic digestion. Fresh grass silage can yield between 250 – 350 Nm3 (volume at Normal temperature & pressure conditions[2]) of biogas per tonne.

2.3.4 Oil seed rape

Oil seed rape is an annual plant whose seeds are pressed to produce oil. Oil seed rape is grown on a rotational basis, typically one year in four. Current yields of rapeseed are about 3.5 tonnes per ha per year for spring sown rape up to 4 tonnes/ha,year for winter sown rape (SEAI, 2004). Approximately 450 litres of oil are extractable from a tonne of rapeseeds (D. Rutz, 2008).

Rape seed oil for energy is generally used for the production of liquid fuel for transport, with minimal processing as pure plant oil (PPO) in modified diesel engines, or as biodiesel after esterification. According to SEAI's Bionergy Maps, there is an existing 7250 ha planted with of oil seed rape, however none of those in Co Clare or Limerick.

2.3.5 Straw

Straw, a by-product of cereal production, is successfully used as a fuel in biomass boilers. Straw is a significant fuel for district heating in Denmark for example. However, the agricultural land in the study area is primarily under pasture and the CSO 2000 Agriculture Census lists only 225 ha of cereals, or less than 1% of the total agricultural land in the area. The potential for straw as a fuel is therefore considered negligible.

2.3.6 Assessment of the potential for energy crops

2.3.6.1 Changes in land use

The total land area in County Clare is 318,784 hectares with 203,450 hectares suitable for agriculture. The total land area in County Limerick (large bodies of water excluded) is 268,992 hectares, with 200,000 hectares or 75% used for agriculture (Limerick County Development Board, 2001). Grazing represents 51% of land cover in Co. Clare and 79% in Co. Limerick. According to the CSO Farm Census 2000, the predominant farm specialisation in Co. Clare is beef production (73%) in addition to specialist dairying (20%) and mixed grazing (7%). In Co. Limerick, 39% of farms are specialised in dairying and 53% in beef production.

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[22] Nm3: normal pressure is generally assumed to be 1 atm while normal temperature may vary between industries, we will assume it is a 20 ºC.

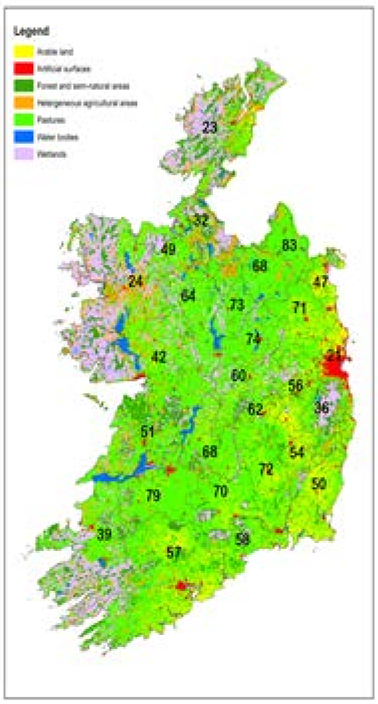

Figure 2: EPA Corine Land Cover (Source: Bord Gais)

Tillage enterprises and in particular cereals are viewed as only marginally profitable and have scope to be substituted with growing energy crops. However, the amount of arable land under cereals is negligible in both counties. Generally, it is considered that specialist dairying is a profitable farm enterprise and there would be little scope in substation of grazing in these farms towards energy crops. By comparison, only 10% of farms of cattle rearing farms are economically viable (Teagasc, 2011).

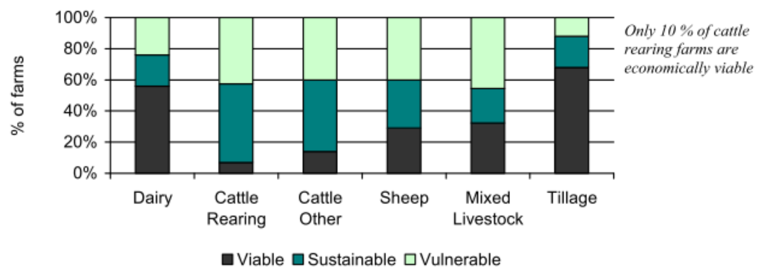

Figure 3: Classification of the 2010 Farm Population by System (Teagasc, 2011)

2.3.6.2 Willow SRC and Miscanthus Potential

On the basis of the above analysis, we assume that the strongest need for diversification and potential for energy crops uptake exists on cattle rearing farms, particularly among farmers at retirement age or part-time farmers. This represents a land pool of approximately 153,000 ha in County Clare and 106,000 ha in Co. Limerick (73% and 53% of agricultural land usage respectively).

Assuming the annual energy yield data published by Teagasc for miscanthus and willow SRC of 45.8 MWh/ha,year (Caslin, “Policy Targets & Bioenergy Scheme”, 12/02/2008), the theoretical potential of energy crops in Clare and Limerick are 7000 GWh/yr and 4855 GWh/yr respectively. This is equivalent to 79% of the current total final energy consumption in the study area.

The table below gives data extracted from the SEAI’s Bioenergy Maps in terms of agricultural land suitable for bioenergy production with high yield potential for energy crops. The statistics generated by the GIS database underlying the maps provide estimates of the total energy potential associated with each energy crop type. Both suitable land and energy potential estimates are broadly in line with the estimates resulting from our own analysis as outlined above.

Table 2: Energy Crop Potential

Energy Crop Type:	Ha of high yielding land:	% of farming land:	Yield (wet, tonne/ha)	Calorific Value (wet fuel) MWh/tonne	Total energy potential (GWh/yr)
Clare:					
Miscanthus:	99,310	47%	16	3.84	6,098
Reed Canary Grass:	132,155	63%	10	3.84	5,072
Willow:	105,827	51%	28	2.44	7,237
Limerick:					
Miscanthus:	66,989	33%	16	3.84	4,114
Reed Canary Grass:	149,908	75%	10	3.84	5,753
Willow:	121,847	61%	28	2.44	8,332

2.3.6.3 Grass Silage for Biogas Potential

According to the agricultural census 2000, there are 174,000 ha and 188,000 ha of grassland (excluding rough grazing considered unsuitable land for grass biogas production) in Co Clare and Co Limerick respectively. Out of that, 52164 ha and 61803 ha are harvested for silage a year in Clare and Limerick.

It is assumed that an annual yield of 12.5 tonne DS (dry solid) per ha per year can be achieved based on two silage cuts per year on regularly reseeded grassland (Smyth, Smyth, & Murphy, 2011). The energy value of grass silage was estimated on the basis of its biomethanisation at a rate of 300 Nm3 of CH4 (normalised cubic meter of methane[3]) per tVDS (tonne of volatile solid), at 90% VS per dry matter weight.

The theoretical potential grass silage resource available if all the silage currently harvested was used for energy purposes therefore 395 million Nm3 of CH4, with an energy content of 3,950 GWh in total (1810 GWh in Clare and 2140 GWh in Limerick). This represents 26% of the current annual final energy demand of the study area.

2.3.6.4 Liquid biofuels

Based on CSO figures for the 2000 census (latest census figures were not available at the time this analysis was performed), the amount of tillage land is negligible in both Clare and Limerick. It is considered highly unlikely there would a significant potential for substitution towards biofuel production in both counties.

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[3] Methane is the combustible compound in biogas, generally present in biogas at a concentration of 50-60%. 1 Nm3 of methane has a net calorific value of c.10 kWh.

2.4 Animal By-products (ABP)

There is a total of 700 thousand heads of cattle in the study area (CSO, 2000). Cattle slurry is captured when the cattle are housed during the winter and is generally stored under the cattle shed or in adjacent above or below ground tanks. There is a marginal amount of slurry captured from the milking parlour. Cattle and cows in particular, are typically housed for 12 to 16 weeks during the winter. The estimated total cattle slurry captured and stored is 2.19 million tonnes of fresh feedstock.

Pigs are housed all year round and slurry is therefore captured and harvestable on an ongoing basis. There c. 60.9 thousands pig units in the study area (CSO, 2000) realising 88.9 thousand tonnes of fresh slurry per year.

Cattle and pig slurry has a low dry matter content at 5-10% depending on the level of dilution with rainwater or washing water. This slurry is generally spread on land within the study area. Anaerobic digestion of this feedstock offers the possibility to produce heat and power as a intermediate step in slurry management, with significant benefits in environmental and agricultural terms.

There is an estimated annual output of c. 7.7 million birds (mostly broilers) in the study area, almost entirely concentrated in Co. Limerick. Poultry litter is mostly made of fresh manure and bedding (straw or wood shavings) and is generally quite dry (between 50% and 80% dry matter). Poultry litter is generally spread on land, but can also be used to produce mushroom composting. As an alternative, poultry litter can be used as feedstock for anaerobic digestion or combustion.

2.4.1 Assessment of the energy potential of ABP

The amount of slurry harvestable (30% of yearly output) and specific biogas output was estimated on the basis of coefficient for different types of cattle extracted from the anaerobic digestion models developed by UCC in 2005 (] Murphy, 2005). Various figures were obtained in terms of specific output of litter, ranging from 1 kg (wet) per bird during its lifetime to 2 kg (wet) per bird (E. Salminen, 2002) (RPS MCOS, date unspecified). We also assumed that poultry manure would be used for biogas production to determine its energy potential. Specific methane yield figures in literature vary from 72 m^3 CH4 per tonne of fresh feedstock (FF) up to 150 m^3 CH4/tFF (E. Salminen, 2002). We have taken an average value of 110 m^3 CH4/t FF.

The table below summarises the result of the energy potential assessment of animal by-products in the study area. In total, the theoretical potential annual biomethane output is estimated at 31.7 million Nm3 with an energy content of 317 GWh/yr, equivalent to c. 2% of the total energy demand of the area.

Table 3: Biogas potential from animal by-products

	Cattle		Pigs		Poultry		Total	
	(t FM/yr)	(m3 CH4/yr)	(t FM/yr)	(m3 CH4/yr)	(t FM/yr)	(m3 CH4/yr)	(m3 CH4/yr)	GWh/yr
Clare	954,765	12,416,717	19,012	246,393			12,663,110	127
Limerick	1,235,447	16,066,994	69,878	905,616	17,435	2,050,629	19,023,239	190
Total	**2,190,212**	**28,483,710**	**88,890**	**1,152,009**	**17,435**	**2,050,629**	**31,686,348**	**317**

2.5 Non-agricultural Organic By-products

An estimate of organic by-products suitable as feedstock for energy generation was compiled for abattoirs in the study area, as well as harvestable domestic and commercial waste sources. In terms of slaughter waste, it was considered that the practical potential lied essentially with belly grass for anaerobic digestion because of the strict interpretation of the Animal By-Product Regulations in Ireland (Smyth, Smyth, & Murphy, 2011). The wet organic fraction of household wastes (food) as well as garden waste collectable within the study area was also included in our estimates, including the fraction of organic waste currently collected in black bins (unsegregated) or brown bins (segregated), home composted or brought the civic amenities. A similar approach was taken for wet organic waste from commercial or industrial premises in the study area. In addition, paper, cardboard and recycled wood were taken as potential fuels. Finally, sludges from wastewater treatment plants (WWTP) were quantified and included as a potential feedstock for anaerobic digestion.

2.5.1 Energy Potential of non-agricultural organic waste

The belly grass feedstock from beef (c.78,000 units) and sheep (43,700 units) kills has been quantified on the basis of data for local abattoirs (36 in Limerick and Clare) and licenced slaughterhouses (2 in Limerick) provided by M. Poliafico (EPA, 2004). Organic wastes from domestic and commercial sources in the study area were estimated on the basis of the Replacement Waste Management Plan for the Limerick/Clare/Kerry region 2009-2010 (King, 2011) and the EPA National Waste Report 2009 and Waste Characterisation report (2008).

We have assumed that all wet organic by-products would be treated by anaerobic digestion to determine their energy potential. We have taken specific potential methane yields figures for each type of by-product according to E. Salminen (2002), R. Alvareza (2008), (Dubrovskis, 2010). We have taken the calorific value of dry by-products such paper, cardboard and recycled wood as expression of their energy value. The table below presents the results of this analysis.

Table 4: Bioenergy potential from industrial and municipal organic by-products.

	Clare		Limerick:	
Wet	Qty (tonnes/yr)	Energy m3CH4/yr	Qty (tonnes/yr)	Energy m3CH4/yr
Organic waste (tWM/yr)	19140	1446979	32080	2425217
Garden waste (tWM/yr)	3,170	389374	6,968	855999
Sludges (tODS/yr):	2603	551232	1805	382222
Abattoirs (tWM/yr)	661	21154	6977	223279
Total wet organics for AD		***2408738***		***3886717***
Dry	Qty (tonnes/yr)	Energy MWh/yr	Qty (tonnes/yr)	Energy MWh/yr
Paper and carboard (tWM/yr):	28887	135263	47707	223389
Recovered wood (tWM/yr):	13407	67654	22047	111251
Total dry organics for thermal:		***202917***		***334640***

The organic by-products quantified above represent potential renewable energy resources estimated at 227 GWh/yr for Clare and 374 GWh/yr for Limerick, equivalent to c. 4% of the total final energy demand in the study area.

3 Wind Energy

Wind energy is the most successful renewable energy technology in Ireland, with approximately 1967.7 MW of installed capacity by August 2011 on the island, and 32 MW installed in Co. Clare and 145.7 in Co. Limerick (www.iwea.com).

Figure 4: Google Street view of wind farm at Booltiagh in Co. Clare. Source: maps.google.com

Two types of wind farm development are considered in this analysis of the wind energy potential in the study area:

- commercial wind farms in the multi-megawatts scale: between 4 and 20 MW, with the average size being 12 MW in Ireland. Existing wind farms are composed of turbines between 800 kW (rotor diameter 50 m) up to 2.5 MW (rotor diameter c. 95 m), with hub heights from 45 m to 110 m;
- off-shore wind energy, with off-shore wind turbines in the region of 5 MW currently and up to 10 MW in development.

3.1 Potential Wind Energy Resource Assessment:

3.1.1 Onshore Wind Energy

The screenshot of SEAI's Wind Maps below presents an overview of wind speeds at 100 m hub height in the study area, as well as the Special Conservation or Protection Areas (orange or green), Natural Heritage Areas (lilac). Round dots indicate the position of existing wind farms.

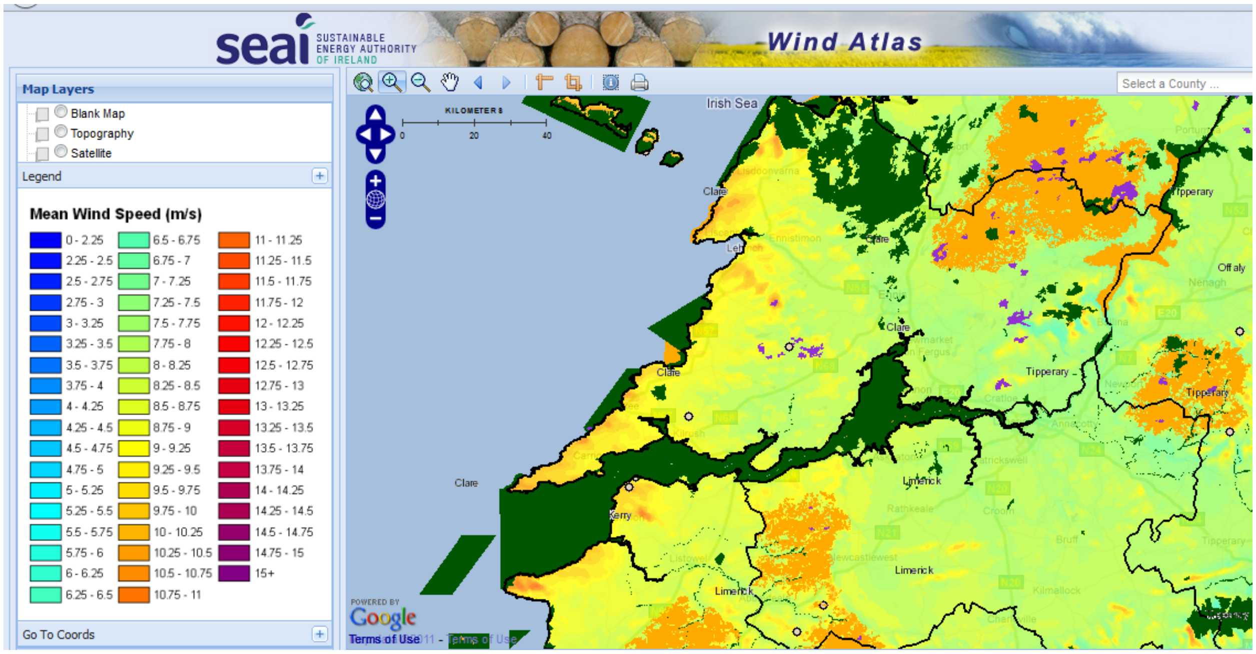

Figure 5: Screenshot of SEAI's Wind Maps for Clare and Limerick.

Wind speeds vary from 7.5 m/s to 10.25 m/s at 100 m hub height, and are typically highest in coastal and elevated locations.

A detailed GIS analysis of the study area would be required to develop an appropriate estimate of the wind energy potential in the study area, taking into consideration wind speeds, proximity to dwellings, designated environmental or heritage areas, accessibility to transmission and distribution grid, environmental impact, etc. This type of analysis is beyond the scope of this study. In some instances, these constraints are integrated in local planning policies.

Clare County Development Plan (CCDP) 2011-2017, Wind Energy Strategy[4], is particularly comprehensive in that regard. It specifies a total of 9150 ha of land as 'strategic for wind' and 38466 ha of land as 'acceptable in principle' for wind energy. Using a power density factor of 10 MW per km2 of land area, there is a theoretical potential of wind generation capacity of 915 MW in strategic areas in Clare and 3847 MW in 'acceptable' areas. Assuming a capacity factor[5] of 33% (Eirgrid, 2007), the theoretical potential for renewable electricity generation in strategic areas is estimated at 2645 GWh/yr and 13765 GWh/yr in acceptable areas, totally 16410 GWh/yr.

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[4] For more details, visit: http://www.lcea.ie/docs/2011/CCIS2011.pdf

[5] Capacity factor: the percentage of potential generation that is actually achieved considering that wind turbines do not work at full capacity all of the time.

It is worth noting that the wind generating capacity in the gate process of approval for grid connection is 127 MW connection for offers accepted and 823 MW for offers not yet approved (Eirgrid, August 2011). Together with the already connected capacity of 32.1 MW, this represent a total wind generating capacity of 982.1 MW in the pipeline, which is roughly similar to the theoretical wind potential in ‘strategic areas’ of the Clare County Development Plan 2011.

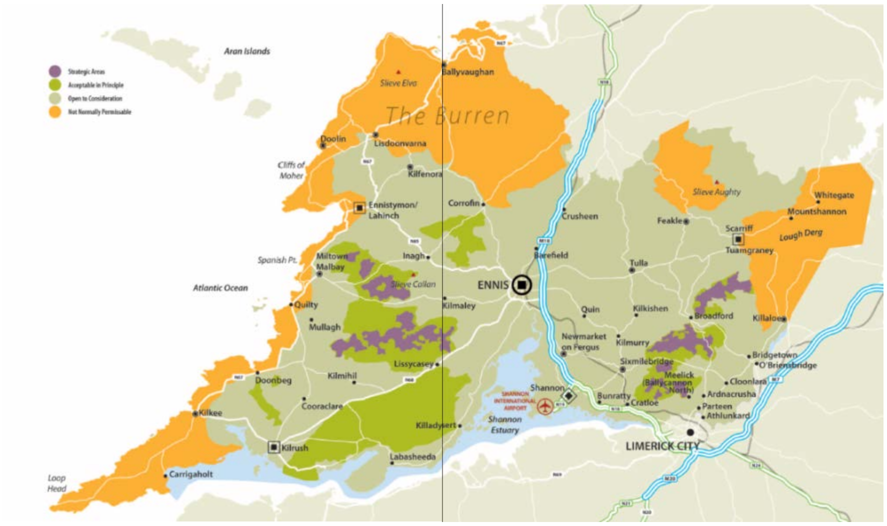


Figure 6: Wind Energy Strategy of CCDP, area designation. Source: (Clare County Council)

The Limerick County Development Plan’s statement on wind energy strategy is less elaborate in its analysis and doesn’t specify wind generation targets. However, it is noticeable that the zones designated as preferred for wind energy development are generally located in low lying areas, where wind speeds are lower and constraining for the viability of wind farm projects. In addition, large parts of elevated areas within the county with higher wind speeds are designated as unsuitable for wind energy development.

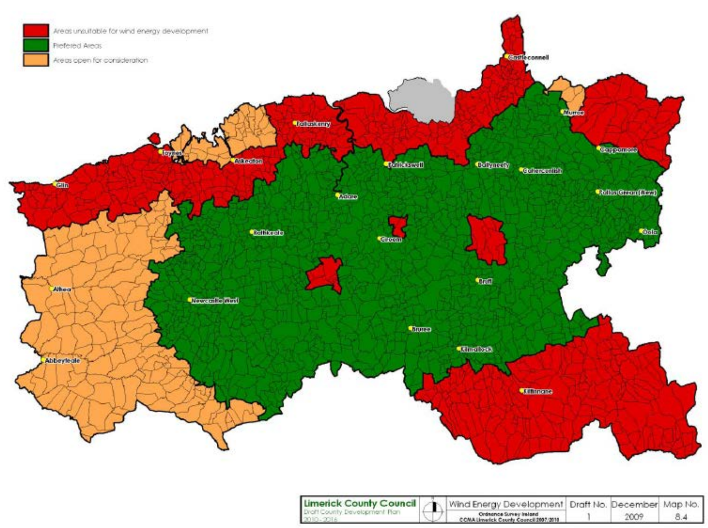


Figure 7: Limerick County Development Plan - Wind Energy Strategy.

A rough measurement of the land area within the 'preferred' zone for wind in the Limerick County Development Plan quantifies it at 1360 km2 or 136,000 ha. At a power density of 10 MW/km2, this gives an estimate of the theoretical potential for wind generation capacity of 13600 MW in Co. Limerick, which could potentially generate 39315 GWh/yr taking a capacity factor of 33%. This is 2.4 times more than in Co. Clare's strategic and acceptable areas.

As per the previous analysis of the wind generation capacity already connected or in the gate process, there are 68 MW of accepted offers and 384 MW not yet approved in Co. Limerick. Together with the existing connected wind generation capacity of 118.7 MW, this amounts to 570.6 MW wind power in the pipeline for the county which could potentially generate 1649 GWh/yr.

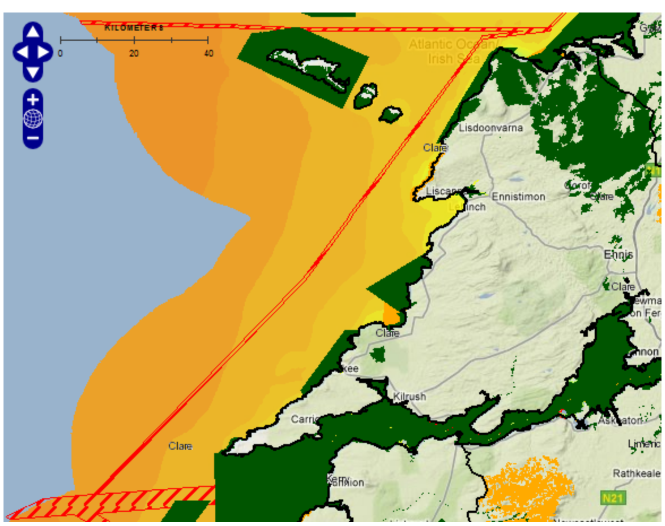
The table below summarises our analysis of the wind energy potential in Clare and Limerick:

Table 5: Wind Energy Potential in the study area.

Total Wind Energy Potential	Clare		Limerick		Total	
	Capacity (MW)	Output (GWh/yr)	Capacity (MW)	Output (GWh/yr)	Capacity (MW)	Output (GWh/yr)
On land designated as strategic, acceptable or preferred in current county development plans:	4762	16410	13600	39315	18362	55725
Based on existing generating capacity and in the connection approval process:	982	2840	571	1649	1553	4489

Each approach gives very different estimates for the wind energy potential. While the estimate based on land area designated for wind in the developments plans of both counties is very theoretical, it is worth noting that the total potential wind energy generation amounts to 370% of the current final energy demand in the study area. At the other end of the scale, wind farms in the grid connection approval process, assumed to represent the level of projects in development in the region, could potentially generate the equivalent of 30% of the total final energy demand in the study area.

3.1.2 Offshore Wind Energy



With its long coastline, County Clare has a substantial offshore energy potential. The offshore area of West Clare has been designated as an Initial Development Zone by the Marine Renewables Industry Association (MRIA), from Loop Head to Hags Head extending to the 12nm limit. The screenshot of the SEAI Wind Energy Maps below presents wind speeds within the 12 nautical miles (c.25 km) limit at 100 m hub height, which range from 9.25 m/s to 10.75 m/s.

Figure 8: Offshore wind speed. Source: http://maps.seai.ie/wind/

Sea bed depth, distance from the shore, navigational channels, designation for protection or conservation (orange and green areas in Figure 8: Offshore wind speed. Source: http://maps.seai.ie/wind/) are key constraints for the siting of offshore wind farms. In terms of sea depth, current or known future piled foundation technology for offshore wind turbines are compatible with sea depths up to 60 m. Floating wind turbines are in development and will allow for siting at greater sea depth in the future. Accordingly, the Strategic Environmental Assessment (SEA) of the Offshore Renewable Energy Development Plan (OREDP) divides the offshore wind potential between ‘fixed’ (10-60 m depth) and ‘floating’ (60-200 m depth).

In terms of distance from the shore, 100 km reflects the upper length limit of Alternating Current (AC) cable technology (for greater distances (beyond 100km) Direct Current (DC) cables would be required with convertor stations on land to convert to AC) (AECOM Ltd, 2011). Offshore wind farm costs also increase significantly with the distance from the shore, generally accompanied by deeper waters. The table below gives scale factors of the cost increases of offshore wind farms as a function of distance to the shore and water depth.

Table 6: Cost increase factors for offshore wind farm - distance to shore and water depth (EEA, 2009)

		Distance to coast (km)							
		0–10	10–20	20–30	30–40	40–50	50–100	100–200	> 200
Depth (m)	10–20	1	1.022	1.043	1.065	1.086	1.183	1.408	1.598
	20–30	1.067	1.090	1.113	1.136	1.159	1.262	1.501	1.705
	30–40	1.237	1.264	1.290	1.317	1.344	1.464	1.741	1.977
	40–50	1.396	1.427	1.457	1.487	1.517	1.653	1.966	2.232

In the West Clare zone, the sea floor drops quickly and brings the 60 m limit within 5 to 10 km from the coast. It is generally considered that the visual impact of offshore wind farms within 10 km is significant. In the UK, offshore developments outside the 12 NM limit will be given preference.

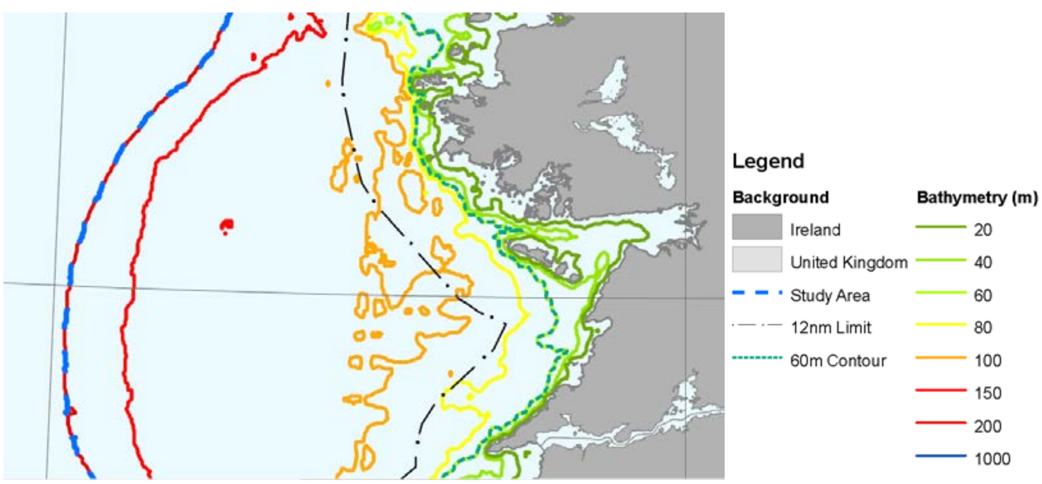


Figure 9: Bathymetry off West Clare (AECOM Ltd, 2011).

In the OREDEP’s strategic environmental assessment, a number of constraints are applied to the theoretical potential of offshore wind based on issues such as impacts on soil and water, biodiversity, population and human health, material assets, heritage, seascape/landscape, material assets, climate, etc. The effect of mitigation measures is also applied and a generation capacity potential is determined. This assessment was carried out for a zone (West Coast Centre) along the coast of Clare and Galway and a theoretical potential > 10,000 MW was estimated for fixed and floating wind.

However, when environmental effects are considered (including mitigation), of which the rapid increase in sea depth (>60 m within 5 to 25 km) is a major factor, the development potential of fixed wind drops to 600 MW with negligible impact. When removing the planned 100 MW wind farm on Sceirde Rocks (Galway), the remaining potential for fixed offshore wind is estimated at 500 MW. This was apportioned between Galway and Clare according to the size of the offshore area along their coastline within the 60 m depth boundary, leaving a potential of 276 MW of fixed offshore wind with negligible impact (equivalent to one large commercial development). Assuming practical full load hours of 3662, array efficiency of 90% and availability factor of 90% (EEA, 2009), this would potentially generate 819 GWh per year (equivalent to 5% of the current final energy demand of the study area).

The potential for floating offshore wind (beyond 60 m water depth and 100 km distance from shore) was estimated at 1625 MW with negligible environmental impact to 3250 MW allowing for the possibility of negative impact. Assuming the same capacity factors as above, this would potentially generate up to 9640 GWh/yr (equivalent to 64% of the study area’s final energy demand).

4 Wave and Tidal Energy

Ocean energy contained in the world's waves and marine tidal currents provides an untapped source of renewable energy. In Ireland both wave and tidal will have a role to play in meeting longer term targets for electricity consumption from renewable sources. The first technologies to exploit this valuable source of energy are currently under development. The Programme for Government and White Paper aims at the connection of 500 MW of ocean energy capacity by 2020.

Figure 10: Wavebob, Irish wave power device. Source: Wavebob Ltd

Wave power is the transport of energy by ocean surface waves, and the capture of that energy to do useful work, in particular electricity generation. Waves are generated by wind passing over the surface of the sea. As long as the waves propagate slower than the wind speed just above the waves, there is an energy transfer from the wind to the waves. There are currently a number of wave power devices being developed in Ireland, including:

- Wavebob (www.wavebob.com)
- Ocean Energy Buoy (www.oceanenergy.ie)

- Hydam – McCabe Wave Pump
- Open Hydro Ltd. http://www.openhydro.com/home.html


Figure 11: Tidal Power Turbine. Source: Sea Gen

Tidal power, also called **tidal energy**, is a form of hydropower that converts the energy of tides into electricity or other useful forms of power. Although not yet widely used, tidal power has potential for future electricity generation. Tides are more predictable than wind energy and solar power. Among sources of renewable energy, tidal power has traditionally suffered from relatively high cost and limited availability of sites with sufficiently high tidal ranges or flow velocities, thus constricting its total availability. However, many recent technological developments and improvements, both in design and turbine technology, are suggesting that the total availability of tidal power may be much higher than previously assumed, and that economic and environmental costs may be brought down to competitive levels.

4.1.1 Energy Potential of Ocean Energy

The following references were used in determining the potential for wave and tidal energy off the Clare coast and Shannon estuary:

- Wave Energy Resource Atlas of Ireland (ESBI, 2005);
- Tidal & Current Energy Resources in Ireland (SEAI, 2005);
- The Offshore Renewable Energy Development Plan – Strategic Environmental Assessment (AECOM Ltd, 2011).

4.1.1.1 Wave Energy:

The following maps show the practical potential for wave energy for Ireland (AECOM Ltd, 2011), and below a zoom-in on the potential off the Clare coastline taken from the Irish Wave Atlas.

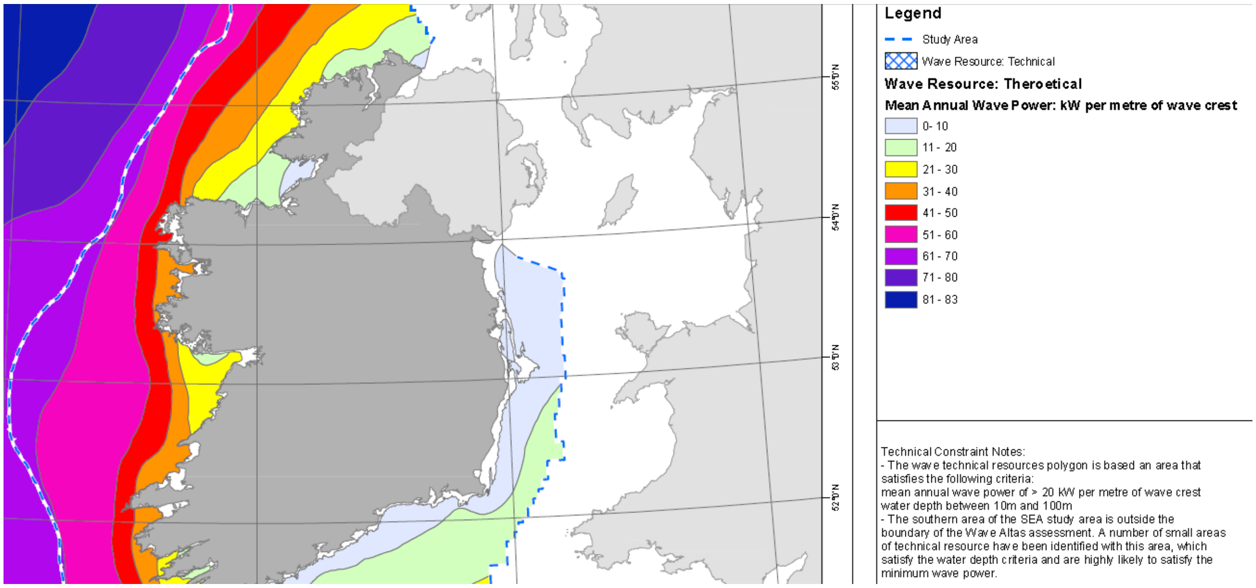


Figure 12: Wave Power Potential off the Irish coast, kW/km of wave crest (AECOM Ltd)

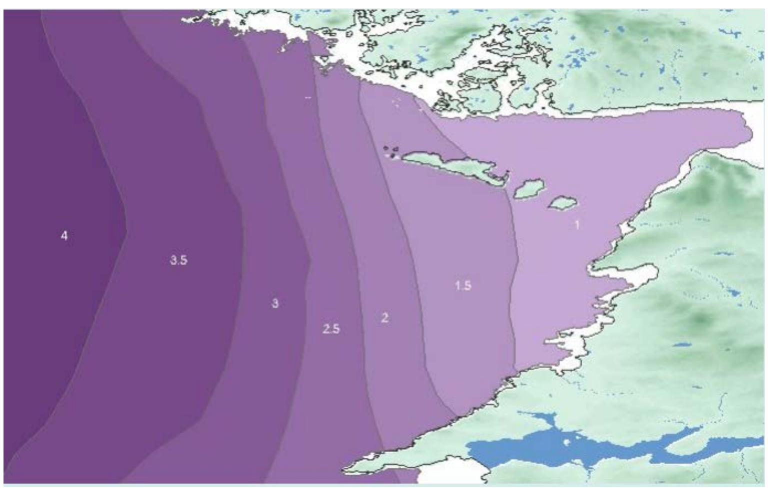


Figure 13: Average practicable wave power in MWe/km of wave crest (Wave Energy Atlas).

Several observations can be made from these:

- A minimal of 20 kW of annual mean power per m, considered the lower limit for technical feasibility, is available immediately off the Clare coast.
- The practical wave power varies from 1 to 4 MWe per km between the 20 m sea depth boundary and the 100 km limit (maximum distance recognised as economically feasible for grid-connection from a wave farm). For illustration purposes, a 100 km of wave crest equipped with wave energy devices at a 55 km distance from the coast would be sufficient to cover the winter electrical peak demand of the study area (350 MW in 2011).
- The average practicable annual wave energy was modelled at 38 GWhe per km of wave front at the 100 km limit off the Clonakilty coast, and 12 GWhe/km at proximity of the coast, based on modelling the output of the Pelamis wave energy device. For illustration purposes, a 400 km of

wave crest equipped with wave energy devices at a 100 km distance from the coast would be sufficient to cover the final energy demand of the study area (350 MW in 2011).

The OREDP-SEA provides an estimate of the practical wave energy potential of 5000 MW for the area within 100 m water depth along the Clare and Galway coast, and 7000 MW between 100 m and 200 m water depth, considering environmental constraints and mitigation measures. When apportioned according to the respective area along both counties coastline, this represents a total wave power potential of c.6600 MW off the Co. Clare coast. This installed capacity could deliver c.19,700 GWh/yr based on a capacity factor of 34% with the Pelamis wave energy device (close to commercial), or 25,400 GWh/yr with a Oscillating Water Colum device currently prototyped at UCC based on a capacity factor of 44% (Dalton & Lewis, 2011). This is equivalent to 130 and 170% of the current final energy consumption in the study area respectively.

4.1.1.2 Tidal Energy

A review of the SEAI's report on the potential of tidal energy in Ireland indicates that:

- Peak tidal current velocities above 2.5 m/s are necessary for the viability of tidal energy devices based on current technologies (2005). The report speculated that it might be 2015 before technical breakthroughs enable the economical extraction of tidal currents at 1.5 m/s or more;
- The practical tidal energy resource lies within the bathymetry (depth of sea floor) zone between 20 and 40 m, outside of shipping lanes, military zones, disposal sites, areas with pipelines and cables;
- On the basis of the above, 11 sites (see Figure 14) offering a practical potential for tidal energy have been selected, none of them close to our area of interest;
- The practical tidal resource in the Shannon estuary is 367 GWh/year.

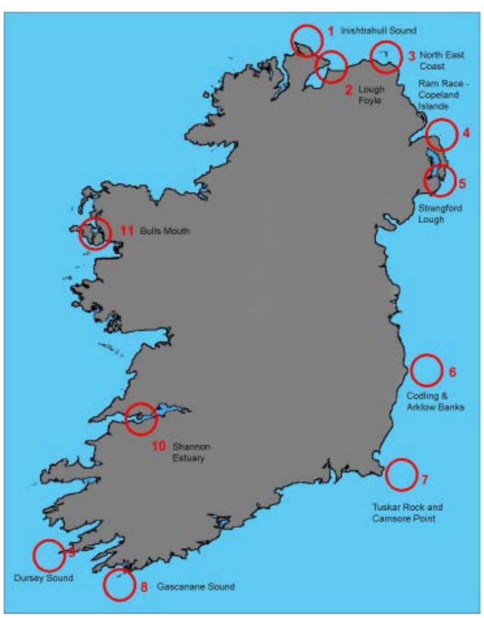


Figure 14: Tidal energy sites selected for offering a practical potential. Source: SEAI

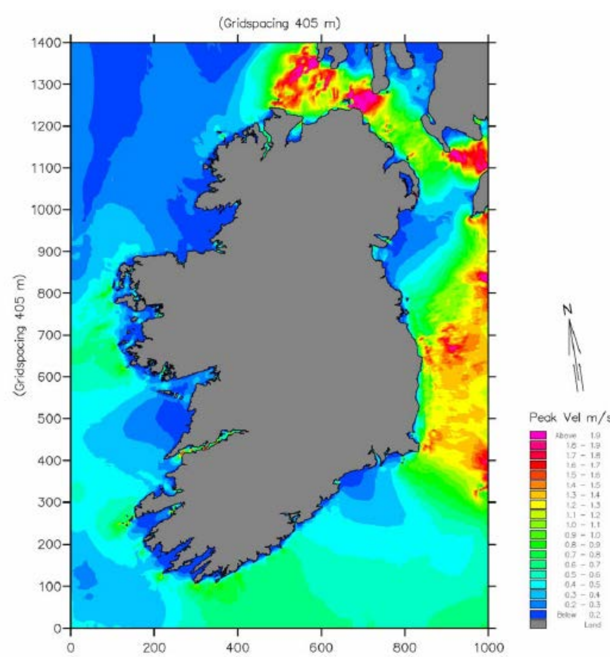


Figure 15: Hotspots for tidal currents. Source: SEAI

Although the OREDP-SEA (AECOM Ltd, 2011) and SEAI estimates that there is an unconstrained tidal energy potential in the Shannon Estuary of 100 MW, any commercial scale tidal development in the estuary is likely to have significant adverse effect on the Lower Shannon Estuary Special Areas of Conservation and Special Protection Area sites. There is also likely to be significant adverse effects on shipping and navigation due to the high intensity of vessels within the estuary. However, there may be opportunities for the area to be used as a location to test tidal devices or for the deployment of a full size demonstration projects (AECOM Ltd, 2011).

4.2 Geothermal Energy

Geothermal energy is extracted from the heat stored in the earth to produce power and/or heat. In Ireland, geothermal applications are limited to low temperature for direct heating. The map below shows earth temperature at 5000 m below ground:

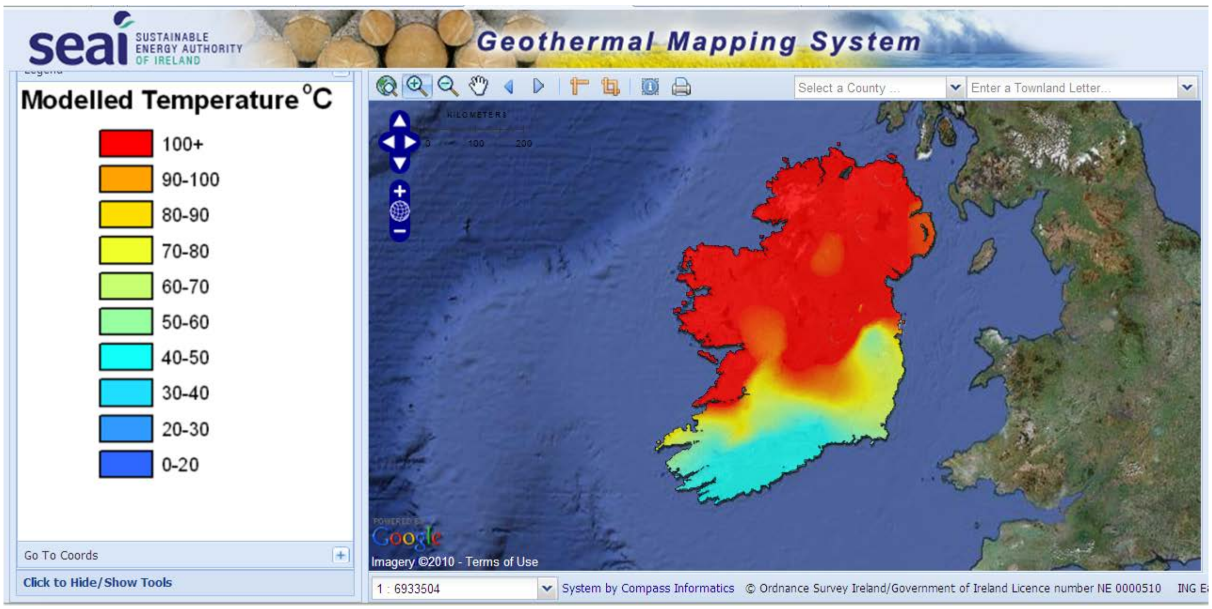


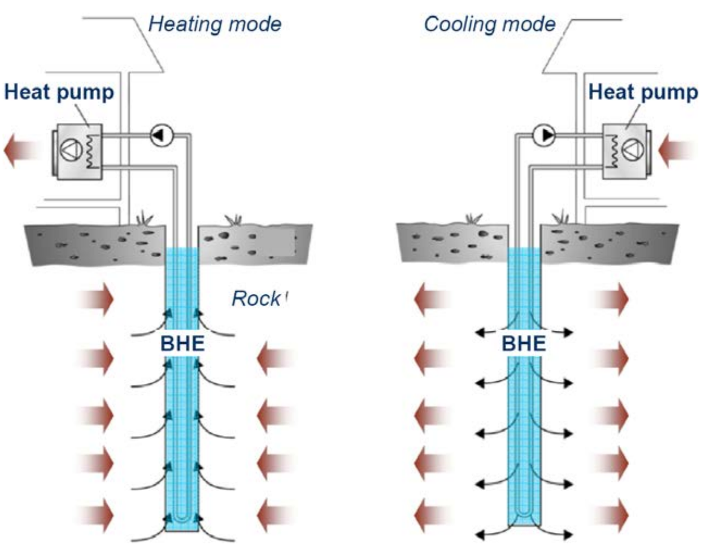
Figure 16: Screenshot of SEAI's Geothermal Mapping System, temperature at 5000 m depth (maps.sei.ie/geothermal/)

According to Alan G. Jones et al (2011), "little is currently known of the potential of Ireland's subsurface geology to provide geothermal energy for district-scale space-heating and electricity generation. Both applications require identification and assessment of deep, permeable aquifers or large-volume, hot, radiogenic granitic intrusions. Ongoing technological advances in utilizing medium-temperature (110–160 °C) groundwaters provide real potential for electricity generation within the upper range of thermal gradients observed in Ireland (28 °C/km). However, such potential can only be realised in the future if deep (4–5 km) geothermal source rocks can be identified within the country's subsurface."

While the SEAI's Geothermal Energy Maps shows a potential for deep geothermal in Co. Clare and North Limerick, a much finer analysis of this potential is required to ascertain where this resource can effectively be tapped into and its suitability for district heating or electricity generation. It is hoped that the IRETHERM project will provide answers in that regard. IRETHERM is an academic-government-industry collaborative project starting in 2011, funded by Science Foundation Ireland, which aims to develop a holistic understanding of Ireland's (all-island) low-enthalpy geothermal energy potential through integrated modelling of new and existing geophysical and geological data. For further details, see http://www.iretherm.ie/

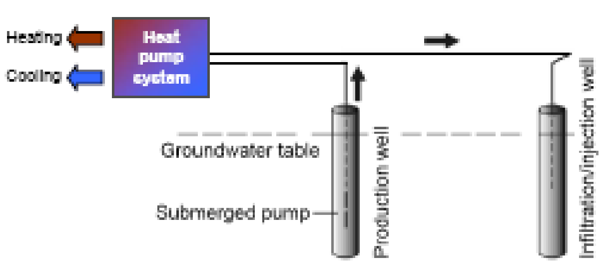
Closer to ground level, ground temperatures are typically a stable 11-12 degrees (100 m deep) and this heat can be exploited using geothermal heat pumps. Heat pumps are generally using a thermodynamic cycle to upgrade low temperature heat pools to higher, usable temperatures. (up to 65 °C for common building applications). Typically, vertical boreholes with closed-loop heat collectors are used in large non-domestic applications.

The heat pump cycle can be reversed to provide cooling, whereby heat extracted for cooling purposes is rejected into the ground through the borehole system, with the advantage of recharging the borehole geothermal potential during the summer for winter use.



Source: Sintef, 2008 [1].

Where groundwater is available in sufficient quantities, it can also be used as a heat source with similar intake temperatures.



Depending on the level of the water table, dry sediment only yields 20-25 W of heat per linear m of borehole (EN 15450) while saturated sediment can yield up to 60 W/m. Consolidated rock can provide a heat extraction rate of 84 W/m (1800 hrs of heat pump operation).

The efficiency of heat pumps drops considerably as the temperature of the heat sink (heat distribution system) rises, so that the typical temperature range of effective application is 30 to 50 °C. However, newer heat pump technology allows achieving up to 65 °C with a reasonable COP and can be successfully applied in the existing building stock, especially if energy conservation measures (insulation, airtightness, efficient ventilation) are applied. It is therefore conceivable that geothermal heat pumps can be applied to a large percentage of the building stock in Co. Limerick and Clare, especially in rural or sub-urban areas where there is better accessibility to the shallow geothermal energy sources (ground or water table).

The potential of using individual geothermal heat pumps as part of a demand management and thermal storage system, in combination with intermittent renewable generators such as wind, might be worth exploring. Geothermal heat pumps are one of the technologies being considered for electrical energy storage such as batteries, pumped hydro, flywheels, etc. with the difference that electricity is stored as heat as opposed to chemical energy, kinetic energy, etc.

5 Conclusions

The following table presents a summary of the results of the analysis conducted to determine the renewable energy potential in the study area.

Table 7: Summary of results of the renewable energy resource assessment.

Renewable Energy Resource (GWh/year)				
Resource	**Clare**	**Limerick**	**Total**	**% of 2020 PES**
Forestry wood fuel (Biomass)	717	240	957	9%
Energy crops: SRC & Miscanthus (Biomass)	6,999	4,855	11,854	116%
Grass silage for anaerobic digestion (Biogas)	1,807	2,141	3,949	39%
Animal by-products: slurry and manure (Biogas)	127	190	317	3%
Municipal and industrial organic by-products (Biogas)	227	374	601	6%
Onshore wind energy (IRES)	16,410	39,315	55,725	544%
Offshore wind energy: fixed and floating (IRES)	10,459	0	10,459	102%
Wave energy: OWC device (IRES)	25,439	0	25,439	248%
Tidal energy (IRES)	0	367	367	4%
Total	**62,185**	**47,482**	**109,668**	**1070%**

Table 8: 2020 NEEAP/NREAP final energy consumption for Limerick and Clare (Connolly , et al., 2012)

2020 NEEAP/NREAP Final Energy Consumption						
Sector (GWh/year)	**Clare**	***Limerick City***	***Limerick County***	**Limerick**	**Total**	
Thermal	1,484	*655*	*2,102*	2,757	4,241	41%
Electricity	750	*314*	*1,021*	1,335	2,085	20%
Transport	1,404	*690*	*1,831*	2,521	3,925	38%
Total	3,638	*1,659*	*4,954*	6,613	10,251	100%

The total figure of 110 TWh of renewable energy resource theoretically available in the study area, including its adjacent offshore area, is encouraging when compared to the final energy demand of the region. However, it is evident that the bulk of that resource lies with on-shore and offshore wind energy as well as wave energy, which together can potentially generate an amount of electricity equivalent to over 9 times the total final energy demand. In this case, the estimates obtained for the renewable energy resource represent final energy in so far that efficiency factors have already been applied to account for the conversion of the primary resource (wind and wave energy) into electricity. The other positive aspect is that electricity is a versatile energy vector which can be used to provide heat, power for buildings and industrial processes, as well as energy for transport with electrical vehicles.

The theoretical potential of bioenergy in the study area has been estimated at 17,680 GWh or 170% of the final energy consumption in the area. The potential consists primarily in woody biomass from forestry and energy crops (72% of total biomass) which can be combusted for the production of heat and/or electricity. Against initial expectations, our analysis indicates that wood fuel from forestry as a limited potential and that a very large substitution of grassland with energy crops such as miscanthus or willow would be required to make a significant contribution to producing the heat and electricity demand of the area from indigenous resource. Grass silage together with other wet organic by-products of agriculture, municipalities and industry can be used effectively and without major alterations to the existing productive systems in place in the region for producing biogas through anaerobic digestion. The theoretical potential of biogas production was estimated to 4870 GWh/yr or 48% of the final energy demand in the study area. Again, biogas is a versatile fuel that can be used to produce heat and/or power, or can be upgraded to be injected in the natural gas grid or used as a transport fuel in compressed natural gas engines. Please note that comparing the bioenergy resource to the final energy demand is only done to illustrate the scale of the resource, and a realistic picture of the actual energetic value of this resource can only be obtained when efficiency factors for its conversion in final energy are applied.

Figure 17 gives a graphical representation of the scale of the renewable energy resource potentially available in the study area and compares it to the current final energy demand.

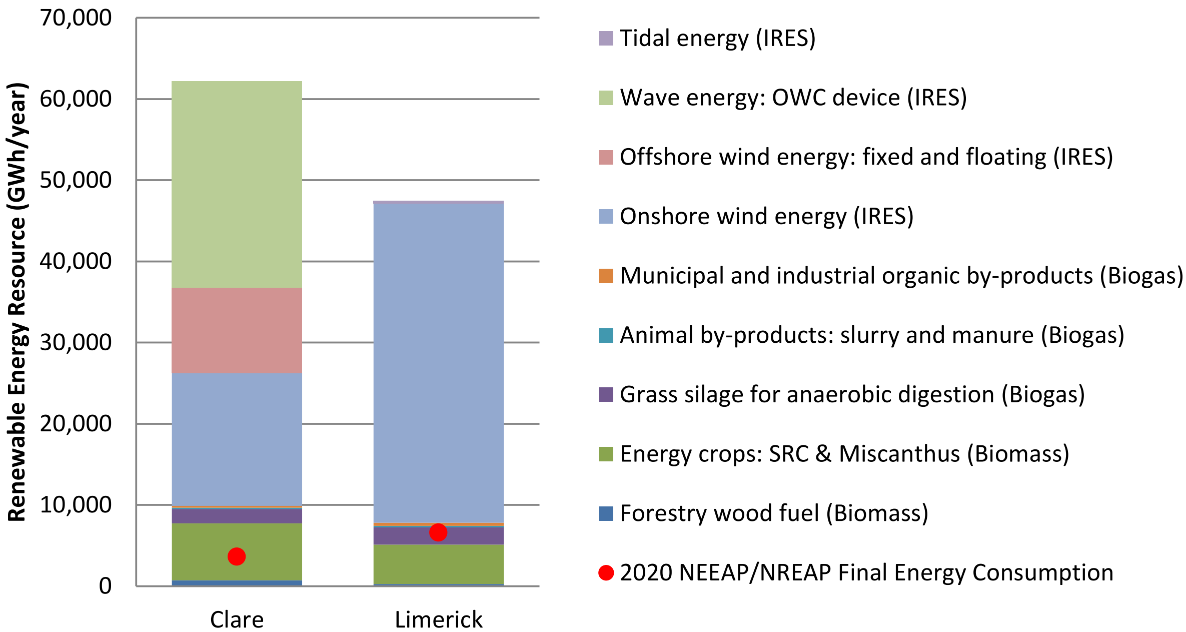


Figure 17: Renewable Energy Resource and Final Energy Demand in Co. Clare and Limerick

In addition, it must be emphasised that the estimates obtained from this analysis are theoretical in that in many cases they haven't been constrained by economic, environmental or socio-cultural considerations. They give an indication of the upper limit of what is technically feasible. The next steps of the analysis which will look at how this resource will fit within an overall energy system optimised on the basis of parameters such as cost-effectiveness, reliability of supply, environmental impact and considering socio-economic effects.

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