Investigation into the feasibility of a West of Ireland Pumped Storage System

AUTHOR

Darren Hughes

A THESIS SUBMITTED FOR THE MASTERS OF SCIENCE DEGREE IN ENVIRONMENTAL SYSTEMS

AT THE COLLEGE OF ENGINEERING,

GALWAY MAYO INSITUTE OF TECHNOLOGY, IRELAND

SUPERVISOR

Seán Moloney

DEPARTMENT OF BUILDING & CIVIL ENGINEERING,

GALWAY MAYO INSITUTE OF TECHNOLOGY, IRELAND

SUBMITTED TO THE GALWAY MAYO INSITUTE OF TECHNOLOGY,

SEPTEMBER 2010

DECLARATION OF ORIGINALITY

September, 2010

The substance of this thesis is the original work of the author and due reference and acknowledgement has been made, when necessary, to the work of others. No part of this thesis has been accepted for any degree and is not concurrently submitted for any other award. I declare that this thesis is my original work except where otherwise stated.

(Signature of Candidate)

Darren Hughes.

Darren Hughes

(Candidate)

(Signature of Supervisor)

Seán Moloney

(Supervisor)

17/10/10

Date

Abstract

Ireland's remote position on the tip of Europe ensures that the country is vulnerable to uncertainty of supply. The reliance on conventional sources of electricity has ensured that escalated prices and high carbon emissions have been witnessed whilst opportunities that inherent resources provide, such as the wind, have not been capitalised upon. The intermittent nature of the wind make it difficult to maximise its potential as in many cases the highest wind speeds are highest when demand is low. The West of Ireland's combination of wind speeds and unique topography makes it suitable for and innovative wind powered pumped storage system, which can essentially regulate the wind generated electricity and integrate further penetration of renewable energy. In addition, its location along the Atlantic Ocean provides further scope for innovation as seawater can be integrated into the system design.

The construction of such an unprecedented project in combination with increased interconnectors has the potential to make Ireland a rechargeable battery for Europe. However, such ambitious plans are at the very early stages and are in direct contrast to current events in the Irish energy market. This study focuses on the feasibility of West of Ireland pumped storage systems. Entailed within this is an extensive desk study, a detailed site selection process and a feasibility study of grid connection. To increase opportunities to identify the best possible site, the feasibility study was focused on the Galway and Mayo areas solely.

Acknowledgements

I would firstly like to express deepest gratitude to my parents and brother for their encouragement and support throughout my study. I would also like to thank my thesis supervisor, Mr. Sean Moloney, for his guidance and advice on the thesis. I also thank the staff at GMIT and in particular, Attracta Brennan for facilitating the study through the summer months.

Table of Contents

Abstract iii

Acknowledgements iv

Table of Contents v

List of Figures vii

List of Tables x

Chapter 1- Introduction 1

1.1Thesis Objectives and Structure 1

1.1.1Hypothesis 2

1.2 Methodology 2

1.2.1 Literature Review 2

1.2.2 Data Collection 3

1.3 Background to the Study 4

1.4 Energy in Ireland 4

1.4.1 The Irish Electrical Grid 7

1.4.2 Irish Energy Providers 9

1.5 The 'Spirit of Ireland' Initiative 10

1.6 Attitudes towards Pumped Storage 11

Chapter 2- Pumped Storage Systems 13

2.1 Introduction 13

2.2 Pumped Storage Systems 14

2.2.1 Components of a Pumped Storage System 14

2.2.2 Design Variables 16

2.2.3 Selecting a Site for a Pumped Storage System 19

2.3 Efficiency of Pumped Storage Systems 20

2.4 Limitations of Pumped Storage Systems 21

2.5 Economics of Pumped Storage Systems 21

2.6 Integrating Wind and Pumped Storage Systems 22

2.7 Conclusions 24

Chapter 3- Site Selection 25

3.1 Introduction 25

3.2 Why the West of Ireland? 25

3.3 Mapping Analysis 29

3.4 Introduction to the Sites 30

3.5 Parameters 33

3.5.1 Topography 35

3.5.2 Head 37

3.5.3 Distance 39

3.5.4 Generating Capacity 40

3.5.5 Accessibility 45

3.5.6 Grid Connection 49

3.5.7 Land Cover 50

3.5.8 Social Setting 54

3.5.9 Landscape 57

3.6 Scoring Card 59

3.7 Ecological Setting 60

3.8 Conclusion 63

Chapter 4- Grid Connection 64

4.1 Introduction 64

4.2 The Exisitng Irish Electrical Grid 64

4.2.1 Turlough Hill 67

4.3 Grid25 and West of Ireland Pumped Storage Systems 68

4.3.1 Update of Electrical Grid 68

4.3.2 West of Ireland Development 69

4.3.3 Pumped Storage Systems Integration 70

4.4 Conclusion 74

Chapter 5- Case Study 75

5.1 Introduction 75

5.2 Energy in South Africa 75

5.2.1 Pumped Storage Site Selection 76

5.2.2 Ingula Pumped Storage System 77

5.3 Discussion 79

5.4 Conclusioon 80

Chapter 6-Coclusion 81

6.1 Conclusions 81

6.2 Future Recommendations 84

References 86

Bibliography 98

Appendix

List of Figures

Figure 1.1: Energy Consumption in Ireland	5
Figure 2.1: Pumped Storage System	15
Figure 2.2: Pumps in series	17
Figure 2.3: Pumps in parallel	18
Figure 2.4: Proposed wind-powered pumped storage system setup	23
Figure 3.1: Regional Distribution of Renewable Capacity	26
Figure 3.2: Wind Map of Europe	28
Figure 3.3: Sites in context	29
Figure 3.4: Site 1	30
Figure 3.5: Site 2	30
Figure 3.6: Site 3	31
Figure 3.7: Site 4	31
Figure 3.8: Site 5	32
Figure 3.9: Peak Loads & Pumped Storage	42
Figure 3.10: West of Ireland Wind Speeds	44
Figure 3.11: Access to Site 1	46
Figure 3.12: Access to Site 2	46
Figure 3.13: Access for Site 3	47
Figure 3.14: Access to Site 4	48
Figure 3.15: Access to Site 5	48
Figure 3.16: Mayo Land Cover	52
Figure 3.17: Galway Land Cover	53
Figure 3.18: Mayo Protected Areas	60
Figure 3.19: Galway Protected Sites	61
Figure 4.1: Installed Wind Capacity by County	66
Figure 4.2: Proposed Expenditure by Region	69

Figure 4.3: Grid Connection Option 1 72

Figure 4.4: Grid Connection Option 2 73

Figure 5.1: Ingula Pumped Storage System 78

List of Tables

Table 1.1: Energy Consumption by Fuel Type	6
Table 1.2: European Electricity Prices	7
Table 3.1: Connaught Wind Statistics	27
Table 3.2: Aran Isles Wind Statistics	27
Table 3.3: Topography Scores	36
Table 3.4: Head Marking Scheme	37
Table 3.5: Head Score	38
Table 3.6: Distance Marking Scheme	39
Table 3.7: Distances to Sea	39
Table 3.8: Generating Capacity Marking Scheme	40
Table 3.9: Site Outputs	43
Table 3.10 Accessibility Marking Scheme	43
Table 3.11: Accessibility Score	45
Table 3.12: Distance Marking Scheme	49
Table 3.13: Grid Connection Distances	49
Table 3.14: Land Use Marking Scheme	50
Table 3.15: Land Use Score	50
Table 3.16: Social Setting Marking Scheme	54
Table 3.17: Social Setting Score	56
Table 3.18: Landscape Marking Scheme	57
Table 3.19: Landscape Score	58
Table 3.20: Scoring Card	59
Table 3.21: Sites and the Protected Areas	60

Chapter 1 – Introduction

1.1 Thesis Objectives and Structure

In this thesis the elements involved in the establishment of a Pumped Storage System (i.e. site selection process and grid connection) will be examined with the goal of determining the feasibility of a West of Ireland Pumped Storage System. Also, the focus of this study is on a large-scale pumped storage system of approximately 1500MW output.

The thesis objectives are as follows:

- Outline the operation, advantages and disadvantages of a Pumped Storage System.
- Identify and analyse suitable sites within Galway and Mayo for the Pumped Storage System.
- Determine the feasibility of grid connection for a West of Ireland Pumped Storage System.

The structure of the thesis consists of 6 chapters. Chapter 1 discusses the background to the study. Entailed within this is a review of the current energy situation within Ireland. The chapter also introduces the possibility of constructing a wind powered seawater pumped storage system in the west of Ireland. The purpose of Chapter 2 is to investigate pumped storage systems in further detail. The benefits and disadvantages of pumped storage will be investigated along with its design, operation and elements such as seawater and wind energy that can be implemented into the system design. Following on from this, Chapter 3 will focus on the site selection process that was carried out in order to critically analyse selected suitable sites for the West of Ireland pumped storage system. Chapter 4's purpose is to study the feasibility of connecting the pumped storage system to the electrical grid to transmit and distribute the power output. Chapter 5 outlines a case study carried out of the South Africa energy situation and the role of pumped storage in meeting targets. Finally, conclusion and further research recommendations will be the focus of Chapter 6.

1.1.1Hypothesis

The hypothesis of this research is "The feasibility of a West of Ireland Pumped Storage System".

1.2 Methodology

Contained within this section is an outline of the methods of research practiced in discovering the feasibility of a West of Ireland pumped storage system. The purpose of this section is to illustrate how the information utilised within the report was garnered. The researcher will also outline the reasoning behind the methods of research utilised.

1.2.1 Literature Review

An extensive desk study of relevant literature to the hypothesis was carried out in order to decipher the current events within the Irish energy market, to investigate operation, benefits and drawbacks of pumped storage systems and to discover how such a system can be integrated into the Irish electrical grid. The review entailed research into both primary and secondary sources of information with textbooks, journals, government publications and technical reports the most common sources utilised. The author also found the internet as a valuable means of collating information due to the relevant sites of the major companies within the Irish energy market. The information collated during this extensive literature review provided a platform for a critical analysis to be carried out and set a basis which enabled the hypothesis to be tested.

1.2.2 Data Collection

Both quantitative and qualitative research techniques were utilised for this report to build on the platform the literature review constructed. It was felt that utilising both methods would enable an optimum overview of the topic.

Quantitative research was central to the site selection process in Chapter 3. The Google Earth programme was extensively utilised to ascertain suitable sites for the pumped storage system. The identification of suitable sites provided many variables which required to be analysed statistically via a formulated scoring system in order to provide concrete material of which a judgement can be made. It is felt that the quantitative research carried out in this chapter was the optimum means of testing the hypothesis as the numerical measurements utilised in the site selection process provided a sensate which abolished any ambiguity which would have existed whilst viewing the selected sites subjectively. Results of the quantitative research will be related to in the qualitative research findings as Chapter 4 will be based on the feasibility of connecting the most suited site for the pumped storage system to the electrical grid.

Two exploratory studies were carried out for the purpose of this report. The first these qualitative research techniques is evident in Chapter 4 and concerns EirGrid's Grid25 strategy whilst Chapter 5 is based on case study of the role of pumped storage in the South African energy industry. These studies were carried out to ascertain current experiences and activities concerning this particular topic. From this, new ideas were able to be identified and applied to this project where appropriate. The findings of the qualitative research enabled the researcher to critically analyse the information and formulate opinions and recommendations.

1.3 Background to the Study

"We simply must balance our demand for energy with our rapidly shrinking resources. By acting now we can control our future instead of letting the future control us" (Jimmy Carter, former US President)

The requirement for alternative sources of energy has culminated in the formulation of the EU renewable energy policy whereby the issue has become one of the primary focuses of policymakers and governments (EurActive, 2007). The increased awareness of climate change issues and the imminent threat posed by Peak Oil are seen as drivers to further penetrate renewable energy (Allen & Randall, 2006). The clamp-down on the use of conventional sources of energy, such as fossil fuels, is evidenced by the international introduction of carbon taxes, which are environmental taxes levied on the carbon content of fuels (Hoeller & Wallin, 1991). From an Irish perspective, the introduction of the carbon tax is essentially placing a price on pollution (The Frontline, 2010). An integral element of offsetting carbon emissions is the harnessing of renewable forms of energy (EIA, 2000). Investment in the Irish renewable energy sector will be required if the Government's outlined target of producing 40% of electricity from renewable sources is to be reached (Department of Communications, Energy & National Resources, 2010a).

1.4 Energy in Ireland

Figure 1.1 depicts 2008's consumption of energy in Ireland from the different sectors. A distinct lack of renewable penetration is evident from the chart. This points to the sizable task at hand of achieving the Irish Governments aforementioned renewable energy targets. However, renewable energy growth is being experienced. In an analysis of Irish capabilities and emerging opportunities in the renewable sector, The IEAA stresses that, "Ireland's environmental goods and services sector is extremely diverse, dynamic and growing rapidly year on year" (IEAA, 2009).

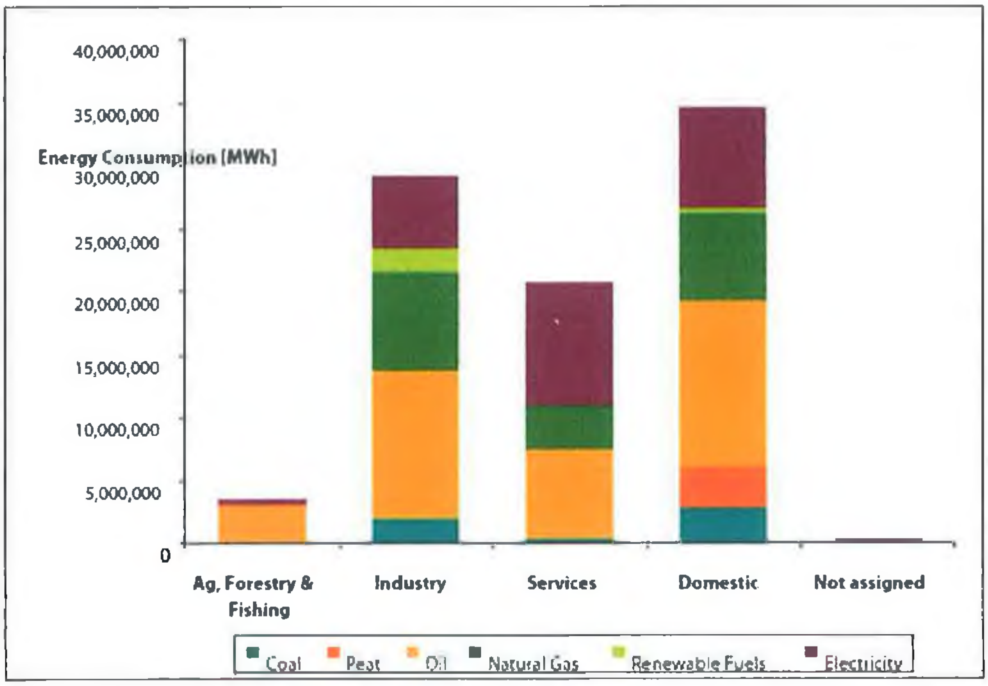


Figure 1.1: Energy Consumption in Ireland (SEI, 2008)

The requirement for a new direction to be taken with regards to energy generation is clear, given that "Ireland currently imports approximately 90 percent of its energy needs (i.e. for electricity, heat and transport)" (Forfas, 2009a). Ireland's lack of indigenous fossil fuel resources (Ruttledge, 2010) could have serious repercussions for the country given its remote position and a minimum interconnection which leaves the country vulnerable to uncertainty of supply (National Offshore Wind Association of Ireland, 2009).

It is clear from Table 1.1 (which shows the European energy consumption by fuel type) that Ireland is currently not taking advantage of opportunities to harness the vast amount of its inherent renewable energy compared to other countries such as Sweden who also possess vast amounts of wind energy potential (Wind Atlas, 2006). Given that Ireland's current consumption of electricity by renewable sources is 14.4%, the task of meeting EU targets of 16% of electricity to be produced by renewable sources by 2020 (Dennehey *et al.*, 2010) is likely to be achieved. However it is not known if the Government's 2020 target will be reached although EurActive state that this target could be achieved (EurActiv, 2010a).

Nuclear energy also presents an opportunity to acquire a zero-carbon source of energy (Energy Resources, 2010). Previously, efforts to construct four nuclear power plants in Co. Wexford were abolished due to the Irish public's negativity towards the plants (MacSimion, 2002). Meanwhile France - a pioneer of nuclear generation - generates in 75% of its electricity from nuclear (World Nuclear Association, 2010), which is half the cost which Irish consumers pay for electricity (O'Connell, 2009). Undoubtedly what is needed in Ireland is a controllable form of clean energy which will reduce the cost of electricity for Irish consumers.

	Coal and lignite	Oil	Gas	Nuclear	Renewables	Industrial waste	Imports-exports of electricity	Total energy consumption (1000 TOE)
EEA members	18.7	36.9	23.7	13.6	6.9	0.2	0.0	1 891 474
EU-25	18.2	37.4	23.6	14.6	6.0	0.2	0.0	1 726 187
EU-15 pre-2004 members	14.7	39.4	24.2	15.3	6.1	0.1	0.2	1 513 568
EU-10 new members	43.2	23.4	19.7	9.2	5.3	0.3	-1.1	212 619
Belgium	11.1	38.0	25.8	21.9	1.9	0.2	1.0	55 785
Czech Republic	47.4	19.7	18.0	15.3	2.8	0.2	-3.2	43 665
Denmark	27.4	40.3	22.5	0.0	13.3	0.0	-3.5	20 676
Germany	24.7	36.4	23.0	12.4	3.4	0.3	-0.1	344 487
Estonia	61.9	19.1	12.5	0.0	9.5	0.0	-3.0	5 456
Greece	29.5	58.0	6.7	0.0	5.1	0.0	0.6	30 160
Spain	15.0	50.0	15.9	11.9	7.0	0.0	0.1	134 055
France	5.1	34.0	14.6	42.0	6.4	0.0	-2.1	270 621
Ireland	16.5	57.1	24.1	0.0	1.7	0.0	0.7	15 269
Italy	8.2	48.6	34.8	0.0	5.9	0.1	2.4	182 007
Cyprus	1.5	97.1	0.0	0.0	1.5	0.0	0.0	2 547
Latvia	2.2	28.5	30.8	0.0	33.4	0.0	5.2	4 378
Lithuania	2.1	26.4	26.5	44.4	7.8	0.0	-7.2	9 004
Luxembourg	1.9	63.8	25.4	0.0	1.4	0.0	7.6	4 196
Hungary	14.0	25.3	44.4	10.6	3.4	0.0	2.2	26 744
Malta	0.0	100.0	0.0	0.0	0.0	0.0	0.0	874
Netherlands	10.9	38.8	44.7	1.3	2.5	0.0	1.8	80 455
Austria	12.1	42.2	23.1	0.0	20.3	0.8	1.5	32 725
Poland	61.3	21.7	12.0	0.0	5.4	0.6	-0.9	94 109
Portugal	13.0	58.7	10.4	0.0	17.0	0.0	0.9	25 331
Slovenia	21.4	35.4	13.1	19.3	10.5	0.1	0.2	6 948
Slovakia	24.2	18.9	30.1	24.4	3.3	0.1	-1.0	18 894
Finland	22.2	27.9	11.0	15.8	21.2	0.8	1.1	37 101
Sweden	5.3	30.4	1.6	34.2	26.3	0.1	2.2	50 878
United Kingdom	16.7	34.5	37.4	10.0	1.4	0.0	0.1	229 822
Bulgaria	38.0	23.3	13.0	23.1	4.9	0.1	-2.4	19 279
Romania	23.5	26.3	37.5	3.1	9.9	0.2	-0.4	40 504
Turkey	26.7	38.4	22.2	0.0	12.6	0.0	0.1	79 721
Iceland	2.8	24.4	0.0	0.0	72.8	0.0	0.0	3 373
Norway	3.5	22.1	23.9	0.0	47.3	0.1	3.0	22 410

Table 1.1: Energy Consumption by Fuel Type (European Environment Agency, 2006)

Ireland's heavy reliance on imported energy combined with the inefficient nature of existing electricity generation plants, has forced the price of electricity to escalate. Ireland's electricity price (relating to businesses and domestic consumers) is compared to other European countries in Table 1.2. As can be seen in the table, the price of Ireland's electricity is the highest in Europe. Essentially, this reliance on imported energy which has resulted in a lack of control over costs (O'Donnell, 2009) highlights a requirement for an effective energy strategy to be formulated. Interestingly, this excessive price of electricity is hampering the success of Irish exporters (Forfas, 2009b). Forfas outlines that Irelands industrial electricity "is 35.5 percent more expensive than the Eurozone average" (2009b) which essentially mitigates the competitiveness of these companies.

	Basic Price	Other taxes (excl. VAT)	VAT	All taxes
	in € per 100 kWh			as % of total price
Portugal	14.86	0.00	0.73	4.7
United Kingdom	14.11	0.00	0.70	4.7
Latvia	6.94	0.00	0.35	4.8
Malta	9.45	0.00	0.48	4.8
Greece	9.00	0.00	0.84	8.5
Luxembourg	14.21	0.80	0.90	10.7
Ireland	**16.90**	**0.00**	**2.28**	**11.9**
Cyprus	13.48	0.22	2.02	14.2
Lithuania	7.37	0.00	1.33	15.3
Czech Republic	8.95	0.00	1.68	15.8
Slovakia	11.52	0.00	2.18	15.9
Bulgaria	6.03	0.00	1.18	16.4
Romania	9.54	0.00	1.87	16.4
Estonia	6.52	0.13	1.21	17.0
Spain	11.64	0.59	2.03	18.4
Croatia	7.93	0.13	1.78	19.4
Poland	10.69	0.62	2.49	22.5
Slovenia	8.61	0.69	1.86	22.8
Belgium	12.86	1.37	2.60	23.6
Finland	8.68	0.74	2.07	24.5
France	9.14	1.25	1.74	24.6
Hungary	9.57	1.23	2.16	26.2
Netherlands	13.00	2.00	3.00	27.8
Norway	10.69	1.30	2.99	28.6
Austria	11.78	2.07	2.77	29.1
Italy	16.74	4.87	2.16	29.6
Sweden	10.13	2.77	3.23	37.2
Germany	12.79	4.85	3.41	39.2
Denmark	10.27	8.94	4.80	57.2

Table 1.2: European Electricity Prices (Finfacts, 2008)

1.4.1 The Irish Electrical Grid

Whilst further penetration of the renewable energy market is imperative if the Government's 2020 targets are to be reached, it is outlined that penetration above the 40% target will create challenges for the electrical grid (EurActiv, 2010a). The problems that are faced concern the electrical grid's stability however further penetration of 60% to 80% would be feasible providing 'technical improvements' were applied to the grid (EurActiv, 2010a). Ruttledge's statement that "the dynamics of the grid are changing" (Ruttledge, 2010) is evident in the form of the 2020 targets but also in the case of ESB's 2004 studies. Results from these studies highlight a decrease in fossil fuel plants efficiency would be expected due to increased wind generation, (McDonald, 2009) which is essentially mitigating the efficiency of a reliable source of electricity (EurActiv, 2010a). Ruttledge also contends that the existing transmission system is under pressure, especially from the expansion in wind harnessing and an upgrade of the grid is needed for further developments in the renewable sector (Ruttledge, 2010). The need for an improved grid is evident from the argument posed by O'Connell (2009). The argument focused on the point that a 1500MW nuclear plant in Ireland would create a pressure on the 7500MW existing Irish grid. Minister Eamon Ryan is in agreement, stating that exporting Ireland's inherent wind energy will require an update of the existing grid and outlined a determination to capitalise on the resource (EurActiv, 2010a). Additionally, EirGrid state that over the past 20 years the capacity of the existing grid has not been altered. During this phase, a 150% rise in demand has been seen (EirGrid, 2008a). This stark statistics highlights the requirement for a revamp of the existing grid. Any development of the existing electrical grid must be a long-term project as "inefficient investment" and "an ineffective grid" are common consequences of short-term targeting (Eirgird, 2008a).

As shown in All-Island map of the country's electrical grid (see appendix) (EirGrid, 2010), only two 400kV transmission lines serve the country - both of which run directly from the Moneypoint generation plant to Dublin. Furthermore, 110kV lines are the solitary high voltage lines serving many areas in the country which essentially serve a distribution grid. Regulating the sporadic nature of wind energy will require the integration of two key components in the Irish grid and across Europe, namely new interconnections and intelligent systems (EurActiv, 2010b). It is outlined that there are many missing interconnectors around Europe, including interconnectors between Ireland and the UK and France (EurActiv, 2010b). The idea behind connecting various grids is due to the intermittent nature of renewable sources and 'uneven geographical nature'. By forming a communal grid, each area of the continent will receive the benefits of northern Europe's wind energy during the winter and the Mediterranean's vast solar radiation during the summer months (EurActiv, 2010b). Further to the interconnection requirements, there is a need to reinforce the reliability of power supply (currently a 99.97% standard) (EurActiv, 2010b). It is stated that investing in storage will increase system flexibility and reduce losses of resources (EurActiv, 2010b).

The state of the grid has a central role to play in the feasibility of a West of Ireland Pumped Storage System. Both Counties Galway and Mayo are both benefactors of the aforementioned 110kV lines (EirGrid, 2010). In comparison, up to 1000kV lines are utilised to transmit Japanese pumped storage systems power to consumers (American Society of Civil Engineers, 1996 whilst 400kV transmission lines are to be utilised in the currently under construction Ingula pumped storage system in South Africa (eThembeni Cultural Heritage, 2008). The author's view is Ireland face a difficult task in achieving exporting goals Minister Ryan alluded to, as the infrastructure is not in place. The integration of a West of Ireland pumped storage system will require an extensive upgrading of the existing grid in order to serve all 32 counties and possibly Europe in future.

1.4.2 Irish Energy Providers

Also playing an integral role in the feasibility of this project are the organisations related to electricity generation and distribution. This includes EirGrid –who were appointed as Ireland's Transition System Operator (TSO) by the state (EirGrid, 2006a)-, whose responsibility is to match supply of electricity with the demand (EirGrid, 2006b). EirGrid are also in charge of Ireland's electrical grid and its interconnectors (EirGrid, 2008a), which will be discussed in Chapter 4. The deregulation entailed a restructuring of electricity supply to promote a competitive energy market and increase in generation efficiency (Yocom & Helms, 2001). EirGrid ensure the supply of electricity by quantifying the amount of energy required and purchasing this quantity from CER (Commission for Electricity Regulation) licensed companies (O'Donnell, 2009c), such as ESB, Bord Na Móna and Airtricity. At the centre of the energy supply process is the EirGrid operated National Control Centre. Here, information regarding each of Ireland's generation plant outputs is gathered and managed by operatives who must then ensure supply even in times of unforeseen events (EirGrid, 2006b.).

Prior to deregulation measures, the ESB was in sole charge of the Irish energy market since it was formed in 1927 (Yocom & Helms, 2001). The government-owned company experienced the highest growth rate in Europe (5% p.a.) which is due to the increase in Irish population, economic activities, employment, and growth in the construction, banking and computer industry (Yocom & Helms, 2001). However, even after deregulation, the ESB are currently in ownership of the existing grid. Recent reports have outlined that a cost of €150million may be required for EirGrid to acquire ownership of the existing grid (O'Halloran, 2010).

1.5 The 'Spirit of Ireland' Initiative

The Spirit of Ireland Initiative is based around the proposals by Professor Igor Shvets, which have been studied extensively by international renowned Academics, Engineers, Architects, Construction and Financial professionals (O'Donnell, 2009b). Professor Shvets proposes the construction of wind-powered sea-water pumped storage systems, sited along the West coast of Ireland. The proposed system entails a selection of up to five U-shaped valleys, whereby dams are to be built on the valleys seaward side and are then to be flooded with seawater from the Atlantic Ocean and will act as a pumped storage systems higher reservoir (McDonald, 2010). Prerequisite valley characteristics include a trough-shape (Shvets, 2010) to facilitate water containment and impermeable rock to retain seawater within the valley thus preventing access to aquifers (Spirit of Ireland, 2009a). Pumped storage systems will be discussed in further detail in Chapter 2.

Spirit of Ireland's planned pumped storage systems will convert wind energy to hydro energy through 18 wind farms (O'Connor, 2010), each consisting of 30 to 35 turbines which will contribute to a 100MW output (The Frontline, 2010). Seawater will be pumped to the plant's higher reservoir in times of lower demand. The load–balancing effect of the pumped storage system will ensure a constant source of renewable energy whilst the need for a lower reservoir is eliminated, as it will be the ocean that will be utilised.

The Spirit of Ireland Initiative argues that a pumped storage system has the ability to be highly profitable and can be constructed at minimum cost through the expertise of Irish based engineers and technicians (O'Donnell, 2009a) goals of the project are to be achieved in two phases. These are:

- Phase 1: Achieving energy independence for Ireland. It is proposed that this is achievable within the first five years.
- Phase 2: It is planned to begin exporting energy (from the pumped storage systems) overseas in the 3 years subsequent to the completion of Phase 1. (Corcoran *et al.*, 2009)

The eventual export of the harnessed energy will embody numerous advantages for the country. The Spirit of Ireland Initiative contends that €5bn/yr (O'Donnell, 2009a) will be made from the selling of the generated electricity thereby invigorating the unstable Irish economy. Furthermore, achieving the aforementioned goals will see Ireland rise to the forefront of the energy industry and essentially become-according to Professor Shvets- a "rechargeable battery for Europe" (Miller, 2010). Reaching the outlined goals through the aforementioned phases will ensure that the country will be perceived as a country which pays its own way. Whilst these goals are highly ambitious, the opinion has been reached that they comprise targets which would entail a complete reversal of the energy situation in Ireland.

1.6 Attitude towards Pumped Storage

The feasibility of integrating a large-scale storage system into the Irish electrical grid was subject to investigations carried out by EirGrid. Results from the study highlight that the most appropriate forms of storage was pumped storage and compressed air energy storage (Department of Communications, Energy & National Resources, 2010a). However, EirGrid's view is that the construction of a pumped storage system would not be worthwhile whilst 40% of our electricity is to be produced from renewable sources. This is due to the anticipated lack of wind curtailment at this stage (Department of Communications, Energy and Natural resources, 2010a). The curtailment of wind is seen when turbines are required to be "shut down to mitigate issues associated with turbine loading, export to the grid, or certain planning conditions" (Wind Energy, 2009). However, whilst looking at the broader picture, the benefits of a pumped storage system are recognised when taking into account 50% renewable penetration (Department of

Communications, Energy and Natural Resources, 2010a). At this stage, a pumped storage system would facilitate higher levels of wind energy harnessing and reduction in production costs. Interestingly, Eirgird state that the optimum approach to take, in terms of economics, would be to increase interconnection and export the wind energy generated. This opinion was formed by taking into account the efficiency loss in pumped storage systems (EirGrid, 2009) (to be discussed in chapter 2).

This study carried out by EirGrid is what seems to mould the Government's opinion when it comes to energy storage. The study is heavily referenced in the Department's National Renewable Energy Action Plan. Outlined within this document is the Departments request of EirGrid to further the studies carried out in the storage field (Department of Environment, Heritage & Local Government, 2010a).

Chapter 2 - Pumped Storage Systems

2.1 Introduction

Pumped storage hydroelectricity is currently the leading energy storage system in use globally with regards storage capacity and cost effectiveness (Miller & Winters, 2009). The pumped storage system was first introduced in the 1890's in Italy and Switzerland (Electricity Storage Association, 2009). The basic setup of this particular project entailed a separate pump and turbine whilst the system's capacity was rated at 1.5MW (Symbiotics, 2008). By 1929, in excess of 40 pumped storage systems were built in Europe. Technological advancements in the systems components such as the reversible pump-turbine lead to increased efficiency of the plants (Symbiotics, 2008). Extreme growth in pumped storage construction was witnessed from the 1960's to the late 1980's due to the oil crisis during that period. These pumped storage systems were introduced to provide a means of energy security (Deane *et al.*, 2009). As it is common in Europe for nuclear power stations to provide power to run pumped storage systems (Symbiotics, 2008), further pumped storage developments were stunted due to the lack of activity in the nuclear sector. However, the turn of the century have seen pumped storage systems gain increased popularity (Deane *et al.*, 2009) as the systems can be utilised as an integrator for the sporadic renewable source of wind energy (Deane, 2009). 2009 figures illustrate that pumped storage accounts for 36GW of the European Union's generating capacity. In comparison, the US' figure of 21.8GW while Japan's installed pumped storage capacity stands at 24.5GW.

Pumped storage systems are an extremely effective means of energy storage which facilitates ease of energy management and frequency control. However, it only accounts for 3% of global generation capacity (90GW) (Electricity Storage Association, 2009). It is speculated that this low figure may be due to the associated high costs of construction combined with the requirement for suitable topography. However, requirements for additional storage plants are evident as the plants can stabilise sporadic renewable energy (Symbiotics, 2008). In comparison, fossil fuels provide 86% of global generating capacity.

Fossil fuels are seen as a ubiquitous source of power globally, due to their availability and simple process of combustion.

2.2 Pumped Storage Systems

Ensuring that the supply of electricity matches demand can be an intricate task to carry out for EirGrid operatives at the National Control Centre (EirGrid, 2006b). As demand must be supplied instantly, it is essential that the efficient management of the load on Ireland's electrical grid is an integral element of the work carried out. As illustrated in Table 1.1, the predominant sources of Irish energy consumption in 2006 are in the form of coal (16.5%) oil (57.1%) and gas (24.1%) while the utilisation of renewable energy (1.7%) is minimal and nuclear is thought to be non-feasible (Ireland's electricity generation from renewable sources has risen to 14.4% (Dennehy *et al.*, 2010) since the publication of the aforementioned statistics). Therefore, the author's opinion is that a niche can be filled by the establishment of a West of Ireland wind powered pumped storage system which would provide the National Control Centre- where the electrical grid is operated in order to match supply and demand (EirGrid, 2006b) - with both a means of load balancing and a controllable source of renewable energy. The integration of a wind-powered pumped storage system onto the Irish grid would also embody further advancements in sustainable development by focusing on renewable energy sources thereby helping to meeting EU 2020 targets. Further drivers for pumped storage systems include "the risk of insufficient capacity" to cope with the growing demand which will place increasing pressure on the electrical grid (Department of Enterprise, Trade and Employment, 2005), in addition to the need for energy supply security, which is an appealing aspect especially given the issue of the looming Peak Oil.

2.2.1 Components of a Pumped Storage System

The fundamental components of a pumped storage system entail two reservoirs - one at a higher altitude than the other - which are connected by penstocks/pipes comprising pumps and turbines (see Figure 2.1). Essentially, the operation of a pumped storage system involves water from the lower reservoir being pumped to the higher reservoir during periods of low demand whereby the cost of electricity is generally low. At its new elevation in the higher reservoir, the stored water acts as potential energy due to pumped storage system ensures that pumped storage systems are viewed favourably in terms of gaining a sustainable source of energy for the Irish electrical grid.

The role of pumped storage systems in electrical grid load balancing will also benefit the existing Irish electricity generation plants. The integration of a pumped storage system in the West will enable plants - who are currently providing for both peak loads and base loads- to provide for the base loads solely (O'Donnell, 2009c), while allowing the proposed pumped storage plant to supply for the peak load demands (O'Donnell, 2009c). Additionally, the construction of a pumped storage system can ensure that older, more inefficient generation plants can be knocked off the electrical grid, thus increasing the overall efficiency of electricity generation in Ireland.

2.2.2 Design Variables

The specification of a pumped storage system's components is a critical element when it comes to maximising system efficiency and meeting energy demands (Azevado *et al.*, 2008). Therefore to achieve the optimum performance level, prudent planning measures must be applied when it comes to the site selection process in the first instance and ultimately the sizing of the turbines, pumps and the piping. The latter will affect the performance of the plant, in particular the pump power, turbine speed and flow rate. The specifics of these aforementioned elements will be central to the level of friction losses in a given plant (Azevado *et al.*, 2008). Friction losses are essentially the effects of loss of pressure during the flow of water in a pipe. Excessive losses in existing pumped storage schemes may require the integration of "large flywheels suspended on magnetic bearings" (Spirit of Ireland, 2009a) to mitigate friction losses. The author contends that the best opportunity for fine tuning the performance of the plant is at the design stage. Traditionally, pumped storage systems consisted of one large pump and turbine. However as advancements were made, alternative component formations were established which placed an importance on the placing of these components as they would have an effect on the performance of the plant. The available options for integrating two or more pumps are as follows (Hammill, 2001):

- Pumps in-series

- Pumps in-parallel
- Reversible pump-turbines

Pumps in-series: The fundamental advantage of incorporating multiple pumps in-series (Figure 2.2) is that it allows each pump to operate at peak efficiency (Hammill, 2001). This may not be achievable with one machine. These formations also facilitate ease of discharge control. Further to this, Hamill (2001) states that the integration of multiple pumps can be advantageous for maintenance purposes or in the case of breakdowns. Due to the formation of the pumps, plant operation ceases once a machine breaks down, in order to allow maintenance to proceed (Hammill, 2001). Pumps in series are illustrated in Figure 2.2.

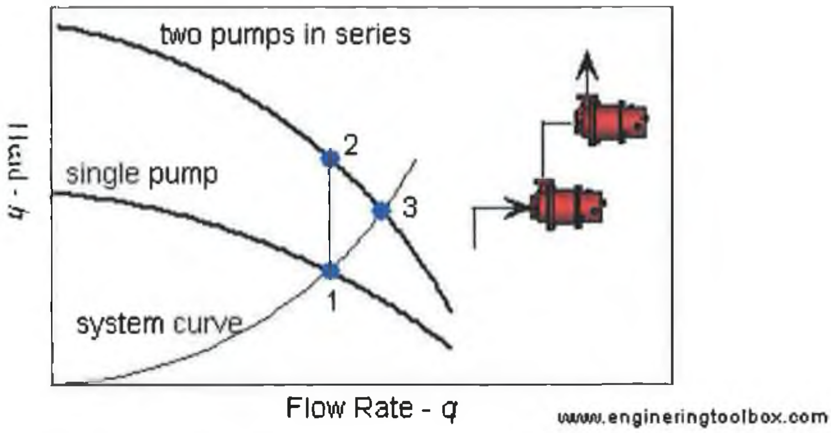


Figure 2.2: Pumps in series (Engineering Toolbox, 2008)

Pumps in-parallel: The integration of parallel pumps (Figure 2.3) is suitable when one pump cannot cope with large volumes of water. Water is pumped into the delivery pipe from each of the pumps individual suction pipe.

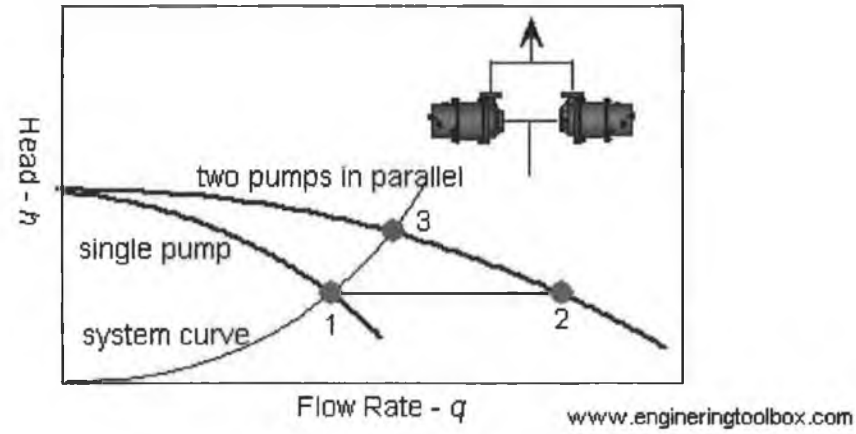


Figure 2.3: Pumps in parallel (Engineering Toolbox, 2008)

Reversible pump-turbines: Another means of increasing project efficiency and cost effectiveness is to utilise reversible pump-turbines, which have become popular in Japan (Deane *et al.*, 2009). These machines are an extremely reliable means of controlling the energy output due to their operating flexibility and their increased efficiency. Deane *et al.* state that one of the prominent advantages of reversible pump-turbines is the "asynchronous motor-generators that allow the pump/turbine rotation to be adjusted" (2009). Advantages of the system include reactive power control and the ability to immediately supply power to the grid.

Adjustable speed turbines: these are machines which can vary its speed during periods of hydraulic head fluctuations (Chaplygina, 2010). The advantage of such a machine over a conventional turbine is that the speed can be varied to work at its optimum efficiency.

With regard to the type of turbines generally utilised in systems comprising pumps in-series or pumps in-parallel, the Pelton wheel is commonly utilised due to its high performance level in high heads (Hammill, 2001) Meanwhile the Kaplan turbine is regarded as the best machine for sites with low head (Kadar, 2009).

2.2.3 Selecting a Site for a Pumped Storage System

The feasibility of a pumped storage system will largely depend on the identification of a suitable site. Whilst the level of site suitability will vary from site to site, the fundamental features that need to be considered in a site selection process include: "a plentiful supply of water with a large enough head to drive the turbines" (Hammill, 2001), site topography and the level of accessibility to the electric grid (Deane *et al.*, 2009).

The majority of pumped storage systems require the construction of both higher and lower reservoir- however pumped storage systems provide scope for innovation in the form of low-head hydropower (where no dams are required) and sea-water pumped storage systems (who's feasibility is to be investigated in this project). It is this difference in height which largely facilitates maximum power. The head of the higher reservoir dictates the force at which the kinetic energy comes into contact with the turbines in the penstocks. This is a critical aspect of the pumped storage system when it comes to power output. The generating capacity of a pumped storage system is calculated as:

$$P_{ow} = \eta .\ \rho .\ g .\ h .\ Q$$

Where:

P_{ow} = rated generating power
η = efficiency (approximately 0.90)
ρ = density of water in kg/m^3
g = gravitation constant in m/s^2
Q = rated generating flow in m^3/s
h = rated generating head (Louwinger, 2008)

This equation will be central to the generating capacity parameter in ∫3.5.4.

Efficiency is also a key element to be considered in the site selection process. Therefore, the chosen site should have relatively easy access to a water source for the reservoirs. Whilst these requirements rule out numerous areas, the west coast of Ireland boasts ideally suited geographical features which are underpinned by the feasibility to integrate innovative variations of a traditional pumped storage plant *(Spirit of Ireland, 2009b)*.

One such variation entails the utilisation of sea-water in the Atlantic Ocean as the lower reservoir. This would reduce the construction costs of a pumped storage system. The Okinawa 30MW plant in Japan is a fine example of a pumped storage system using the Ocean as a lower reservoir. This 1.5MW system has been in operation since 1998 (Martifer Renewables, 2009). The upper reservoir of the pumped storage system is located 600m from the shore, whilst the head is calculated at 150m (EPDC, n.d.). The feasibility of constructing a sea-water pumped storage system in the west of Ireland is aided by the existence of "bowl shaped glacial valleys were carved out in the last ice age" (Spirit of Ireland, 2009a). Furthermore, there is potential to harness the vast amounts of wind energy which the West coast of Ireland possesses (Spirit of Ireland, 2009b). Spirit of Ireland Initiative state that "Ireland has the same potential wealth per capita as Saudi Arabia of untapped natural energy" (O'Donnell, 2009a), which currently is wasted for the most part. The implementation of a wind-powered pumped storage system along the West coast of Ireland would support the harnessing of such energy as well as realigning attitudes towards renewable sources of energy.

2.3 Efficiency of Pumped Storage Systems

The function of a pumped storage system means that the plant is a net consumer of energy (Twenty First Strategies, 2009). As an example, for a particular plant to produce 1kWh of electricity at a period when consumption is high, a larger amount of off-peak energy will be required to pump the water up to the higher reservoir. However the operation of pumped storage systems are still favourably viewed as efficient use is made of the off-peak electricity leading the plant to be an extremely cost-effective means of large energy storage (Renewable Energy World, 2010). One of the primary technical concerns of pumped storage systems is the plant's efficiency. As previously stated, pumped storage systems are net consumers of energy. Therefore, to reach the maximum performance level, plants must regain as much as possible, the power they consume. The efficiency of a typical pumped storage system can vary from 70-90% (Electricity Storage Association, 2009; Louwinger, 2008).

2.4 Limitations of Pumped Storage Systems

For all of its appealing aspects, there are a number of other factors that need to be taken into consideration when considering the feasibility of a pumped storage system One interesting point raised by RePower (2010), a European alternative energy company, concerns the issue of the effect of the pumped storage system on the environment. Environmental concerns include the flora and fauna in the area as well as the marine life of the ocean (that is being utilised as the lower reservoir) (RePower 2010). Further to this, developments in a given area can have an adverse effect on the quality of water within the area which would be affected by runoffs from the work. Also, the site selection process may identify a site where existing housing is established. This in turn may intensify planning complications. These issues will be discussed in further detail in chapter 3.

As the construction of a pumped storage system is a physically large project, concerns exist surrounding the issue of flooding in the selected area. This brings in the importance of the structural engineer in a project of this magnitude. Although highly unlikely, it is anticipated that the event of a collapse of a dam would be utilised as a counter-argument from opposition to the construction of the plant.

2.5 Economics of Pumped Storage Systems

The magnitude of a pumped storage system project also means the integration of pumped storage systems into the Irish grid, which is anticipated to be a time consuming process. Pumped storage systems are renowned for long construction programmes as well as high costs of construction. This could be viewed negatively in today's economic climate or conversely, could be seen as a project which could invigorate the industry by providing jobs (O'Donnell, 2009a.). Additionally, the decrease in construction costs during the recession raises the argument that now may be the time to build such a large scale project. Other economic benefits of a pumped storage system project can include the supply of low-cost electricity. The Spirit of Ireland Initiative outlines that the optimum plan would entail power companies such as the ESB and Airtricity to "run their base load at full load for 24 hours a day" (O'Donnell, 2009c). This underpins the earlier point from §2.2.1 regarding electricity generation plants and ensures an efficient and systematic supply of electricity for consumers. Effectively, the electricity generation plants would need to collaborate with the pumped storage system to even out the load on the electric grid. Furthermore, Ireland's inhabitants reliance on fossil fuels will be mitigated from the plants implementation which will in turn, save capital spent on the resources.

To estimate the cost of a large-scale pumped storage system in Ireland, it was necessary to study US cost per kW figures. Leyland (2009) outlines that the construction of a pumped storage system costs $1500 per kW. Therefore, it is estimated that the cost of a proposed 1500MW pumped storage system would be approx. €1.75bn.

2.6 Integrating Wind and Pumped Storage Systems

Although wind is technically available 24 hours-a-day, the core argument against harnessing wind energy is the fact that wind energy is intermittent (Deane, 2009). It is commonly recorded that wind may not blow when required (during peak demand times), while it is at its most powerful when it is not required (at points of low demand) (Deane, 2009). Given that pumped storage systems are particularly suited to wind integration (due to their flexible and robust nature as well as fast response times (Deane, 2009)), the location of the Spirit of Ireland's proposed 18 wind farms across a wide geographical area along the West coast is also an important element in investigating the feasibility of a West of Ireland pumped storage system. Basically, it is inevitable that a degree of wind power will be harnessed to pump the lower reservoir's water capacity. Utilising the harnessed wind energy to power the pumped storage system will facilitate a flow in the grid of constant renewable energy as well as providing significant steps towards reaching the government target of 40% of Ireland's electricity from renewable sources by 2020 (Melia, 2010). It has to be pointed out that electrical back-up is essential to facilitate pumping during calm days.

Studies from the Spirit of Ireland (2009a) indicate that proposals for the initiatives' energy targets required the construction of 2500 wind turbines of 3 MW output located across a wide geographical region. Constructing these 2500 turbines would consume approximately 1% of the Irish land mass (Spirit of Ireland, 2009a), However, with development of larger wind turbines such as Enercon's E-126- which has a rated power output of 6MW

(Enercon, 2007)- the number of installed turbines to power the pumped storage system can be significantly reduced.

When taking into account the output from the wind farms in addition to the vast amounts of land required, the integration of wind energy into large-scale projects such as the Spirit of Ireland's proposed pumped storage system is an effective method of maximising the inherent potential energy along the West coast of Ireland. The role of wind farms in a wind-powered pumped storage system is depicted in Figure 2.4. The image portrays the wind farms connection to the pumped storage system where the wind farms generated power is utilised to pump seawater to the higher reservoir.

Figure 2.4: Proposed wind-powered pumped storage system setup (Spirit of Ireland, 2009c)

The harnessing of wind energy harnessing in Ireland is increasing. This is evident in the cases of the proposed introduction of a further 250 wind farms, with the majority situated along the West coast (Melia, 2010). The current number of 117 wind farms is being increased as the Government aim to reach 2020 targets. As this will inevitably lead to large levels of wasted energy, the author contends that achievement of sustainable development may not be feasible without a control system such as a pumped storage system to regulate the energy harnessed by the wind.

2.7 Conclusion

Pumped storage has evolved into a mature technology since its introduction in the 1890's. This evolution is evidenced by the advancements in the design variables of its components- which have increased efficiency ratings- and the system itself. As it is expected that pumped storage popularity is about to rise, it is a fair argument that current decisions made regarding pumped storage may shape the way electricity is utilised for years to come. With regards Ireland's electricity generation, allowing a wind-powered pumped storage system to provide for peak loads whilst the existing generating plants operate at optimum efficiency to supply base load power is an improved means of supplying electricity and is at least a step in the right direction. Pumped storage's comparatively low generation capacity is quite surprising particularly when storage capacity and cost effectiveness are taken into account. Furthermore, the system's ability to balance the electrical load and provide a means of controlling renewable energy are factors which are likely to encourage a higher generating capacity from pumped storage.

Findings from the research indicate that a West of Ireland pumped storage system is extremely feasible. The West's topography and wind resources, the possibility of integrating wind-power and sea-water into the technology ensures that- should the project be executed successfully- the system will be viewed as an exemplar for future pumped storage developments. The utilisation of the renewable wind resource also bodes favourably for the Governments outlined 2020 targets. Additionally, the reduction in pressure on the grid also contributes to the pro-pumped storage argument, which is an extremely positive aspect especially when considering the existing Irish grids difficulty with renewable integration.

Chapter 3 – Site Selection

3.1 Introduction

Central to investigating the feasibility of a West of Ireland pumped storage system is the identification and analysis of suitable sites within the area. The aim of this practice is to identify the most applicable site for a large scale West of Ireland wind-powered pumped storage system. This chapter's purpose is to outline the process taken in analysing suitable sites for the pumped storage system to be located. Factors that will be discussed include the West of Ireland's suitability to the project, the site identification measures that were practiced plus the different parameters that were deemed appropriate for the site selection process.

3.2 Why the West of Ireland?

There are major opportunities for innovative, wind-powered pumped storage system in the West of Ireland due to the vast wind resource in the area (as illustrated in Figure 3.1) and the suitability of many U-shaped valleys which have the ability to act as higher reservoirs (Spirit of Ireland, 2009a). Attached in the appendix is a Wind Speed Map of the mean wind speeds at 100m across Ireland. It indicates towards numerous regions along the Atlantic coast- both onshore and offshore- where mean wind speeds are in excess of 21.3mph. From this map, the wind speeds between Ireland's East and West coasts can be compared. It is interpreted that the only regions to harness wind of the aforementioned speeds is in the Wicklow Mountains. However, the feasibility of seawater pumped storage system in this area is mitigated as the site is deemed to be too far inland to utilise the Irish Sea as a lower reservoir (Spirit of Ireland, 2009a). Furthermore the West of Ireland boasts 'a high ratio of wind to calm days' (Ireland Wind Turbine, 2010) which lessens the intensity of the intermittency. The volume of the wind in the West of Ireland is also high (Ireland Wind Turbine, 2010) which will ensure that harnessing the source will be easier. Currently, there are 23 Connaught-based wind farms connected to the electrical grid

(Melia, 2010). Therefore, due to the high volume of wind resources, it is inevitable that significant amounts of power can be harnessed by the 23 farms plus the proposed 46 new wind farms planned to be connected by 2020 (Melia, 2010) as "wind will be blowing somewhere all the time" (Larson, 2009). Figure 3.1 highlights the Regional Distribution of Renewable Capacity where Galway and Mayo are categorised as North West. It reinforces the opinion that the West of Ireland is the optimum location for harnessing renewable sources of energy.

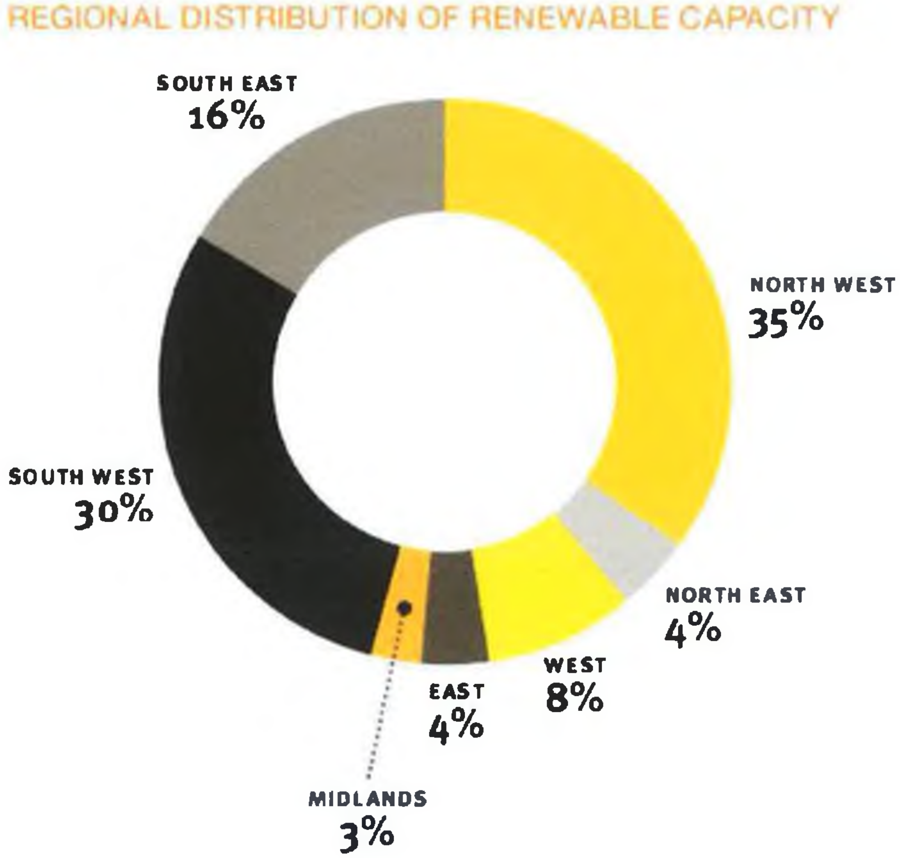


Figure 3.1: Regional Distribution of Renewable Capacity (EirGrid, 2008a)

Table 3.1 enables Connaught's wind probability to be studied. The figure illustrates that the average wind probability across 12 months for province is 43%, with March being the month where the intensity of wind is at its highest. This again compares favourably to the Wicklow Mountains area where the wind probability rating is significantly lower at 16% (Wind Finder, 2010a). However, when comparing Connaught's wind probability data to the statistics attainable from the Aran Islands, the vast potential for harnessing offshore wind is evident. Table 3.2 shows that the wind probability is significantly higher in this area. Further to this, it is also evident that the average wind speeds at the Aran Islands are higher than those in the Connaught region, which is a favourable asset to possess when it comes to the rated speed of wind turbines (Energy Bible, 2008). Wind turbines rated speed- "the minimum wind speed at which the wind turbine will generate its designated rated power"- is in the 25-35mph region (Energy Bible, 2008). Therefore, due to the wind speeds and probability, the consensus is formed that the West of Ireland is the optimum area in Ireland to harness wind energy.

Connaught (CONAUGHT)
Statistics based on observations taken between 2/2002 - 6/2010 daily from 7am to 7pm local time.

Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	SUM 1-12
Dominant Wind dir.													
Wind probability >= 4 Beaufort (%)	46	41	53	46	49	44	38	40	39	42	45	41	43

Table 3.1: Connaught Wind Statistics (Wind Finder, 2010b)

West of Aran Isles (ARANISLS)
Statistics based on observations taken between 10/2003 - 9/2007 daily from 7am to 7pm local time.

Month of year	Jan 01	Feb 02	Mar 03	Apr 04	May 05	Jun 06	Jul 07	Aug 08	Sep 09	Oct 10	Nov 11	Dec 12	SUM 1-12
Dominant Wind dir.													
Wind probability >= 4 Beaufort (%)	60	72	75	55	63	57	52	59	84	77	87	83	70

Table 3.2: Aran Isles Wind Statistics (Wind Finder, 2010c)

In terms of utilising the pumped storage system as a regulator and as a tool to export energy, Figure 3.2 indicates that there is scope to harness offshore wind energy and export the energy to areas with lesser inherent wind resources. This image portrays the European wind resources where it is visible that the West Coast of Ireland possesses the best source of wind energy in Europe along with Scotland and the Scandinavian region where wind speeds in excess of 8.5m/s are recorded along the sea coasts. The West of Ireland has the resource to facilitate maximum penetration of wind energy which will ensure that the region has a critical role to play in a 'Super Grid' (Mainstream Renewable Power, 2010).

Wind Resources at 50 (45) m Above Ground Level

Colour	Sheltered terrain		Open plain		At a sea coast		Open sea		Hills and ridges	
	m/s	W/m²	m/s	W/m²	m/s	W/m²	m/s	W/m²	m/s	W/m²
	>6.0	>250	>7.5	>500	>8.5	>700	>9.0	>800	>11.5	>1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0-8.5	400-700
	<3.5	<50	<4.5	<100	<5.0	<150	<5.5	<200	<7.0	<400
			>7.5							
			5.5-7.5							
			<5.5							

Figure 3.2: Wind Map of Europe (Wind Atlas, 2006)

Wind availability is an important aspect of this particular project as the resource will be harnessed to power the pumped storage system. Taking the pre-discussed wind availability and the proposed 250 wind farms (Melia, 2010) into account, the harnessing of wind energy is not deemed to be a disrupting issue in terms of ascertaining the feasibility of a West of Ireland pumped storage system and will therefore be excluded from the parameters of the site selection process.

Further innovation in the pumped storage area is feasible in the West of Ireland. This innovation stems from the existence of U-shaped valleys along the west coast. These valleys were created during the ice age (McDonald, 2010) and can be utilised as the pumped storage Systems higher reservoir while the Atlantic Ocean takes the role as the lower reservoir- similar to the work done at the Okinawa Pumped Storage System (Fujihara *et al.*, 1998). Locating suitable sites was the goal of the mapping research carried out in the site selection process. The next section of this chapter is a synopsis of this study along the West coast of Connaught.

3.3 Mapping analysis

The first step that was taken in the Site Selection Process was to study the topography of the West coast of Ireland. This was done by using Google Earth extensively. The programme enabled a clear view of shape of West coast valleys to be attainable. At this stage of the process the main factors that were taken into account were the physical shape of the valleys and the distance to the Ocean which are important elements when it comes to reservoir suitability (Statkraft, n.d.) and losses (Azevado *et al.*, 2008). From this, the five best sites (i.e. sites with suitable bowl-shape features located as near to the sea as possible) within the Galway and Mayo area were selected to be subject to a scoring system that will determine the most suitable site for the pumped storage system. Figure 3.3 illustrates the sites locations in context of the Connaught region. The sites are introduced in ∫3.4.

Figure 3.3: Sites in context (Google Earth, n.d.)

3.4 Introduction to sites

The first two sites- portrayed in Figure 3.4 and Figure 3.5- that were selected for study are in the Achill area of Co. Mayo. The area possesses steep topography characteristics coupled with a "relatively uniform upland moor appearance" (Mayo County Council, 2008a). Achill Island itself is renowned for its constantly visible coastline (Mayo County Council, 2008a). Site 1 is located at Keel West, Achill, Co. Mayo whilst the Site 2 is situated at Corraun Hill, Achill, Co. Mayo. Site 1 is located 2.3km from the sea at an elevation of 187m whilst Site 2 is situated 2.9km from the sea at an elevation of 178m. Enclosing the whole valley would provide an estimated 225 x 10^6 m^3 of storage capacity for Site 1 and 350 x 10^6 m^3.

Figure 3.4: Site 1 (Google Earth, n.d.)

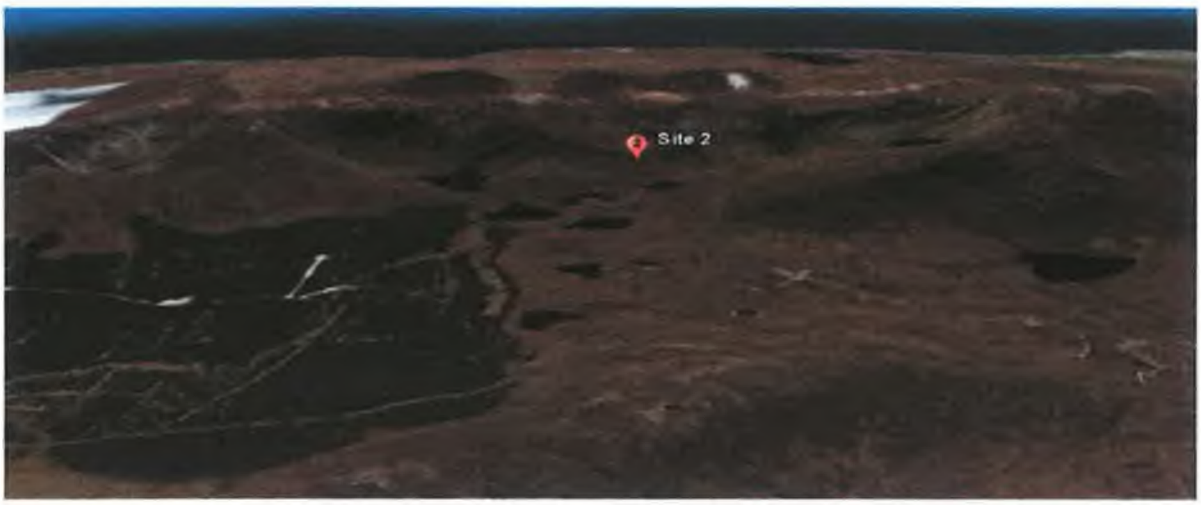


Figure 3.5: Site 2 (Google Earth, n.d.)

The third selected site is situated on the Clew Bay coastal area, near Newport, Co. Mayo (see Figure 3.6). With regards topography, the ground is tilted towards Clew Bay (Mayo County Council, 2008a). This particular site is located at Carheenbrack, Newport, Co. Mayo. Full enclosure of the valley would yield an estimated 775 x 10^6 m^3 of storage. The site is located 2.75km from the sea at an elevation of 116m

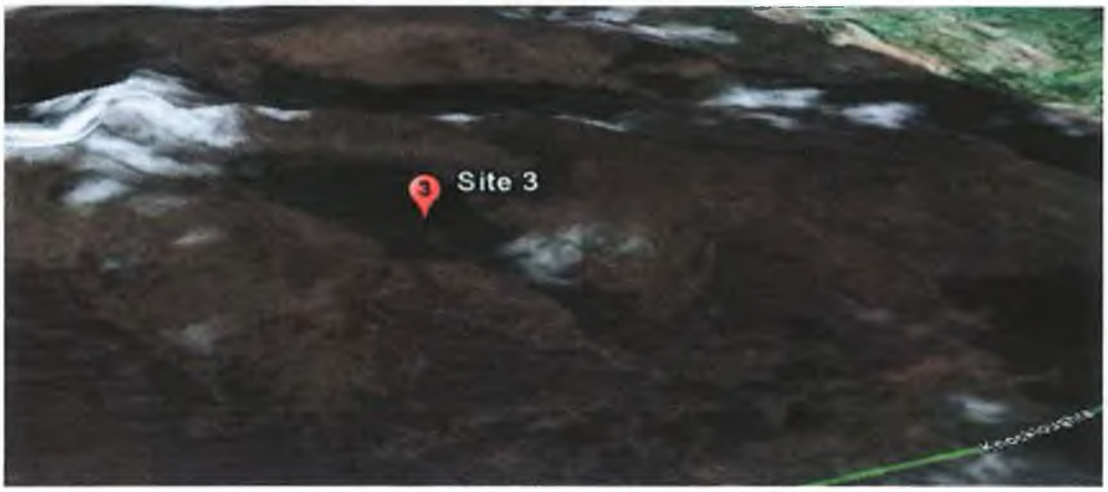


Figure 3.6: Site 3 (Google Earth, n.d.)

Site 4 (see Figure 3.7) is located at Killary Harbour in the Southwest Mountain Moorlands of Co. Mayo. Typical features of the area include "smooth steep slopes, broad valleys and ridge top plateaux" (Mayo County Council, 2008a). Erecting the dam across the open end of the valley will provide a storage capacity of 480 x 10^6 m^3. The site is located 1.8km from the sea at an elevation of 190m.

Figure 3.7: Site 4 (Google Earth, n.d.)

Site 5 (Figure 3.8) is located in the West of Galway's Connemara region which is an area that possesses landscape of "outstanding value rating" (Galway County Council, 2009). The site is located at the Twelve Pins, Connemara, and 6.5km from the sea. The elevation of the site is 170m. Enclosure of the entire valley would facilitate in excess of 1,800 x 10^6 m^3.

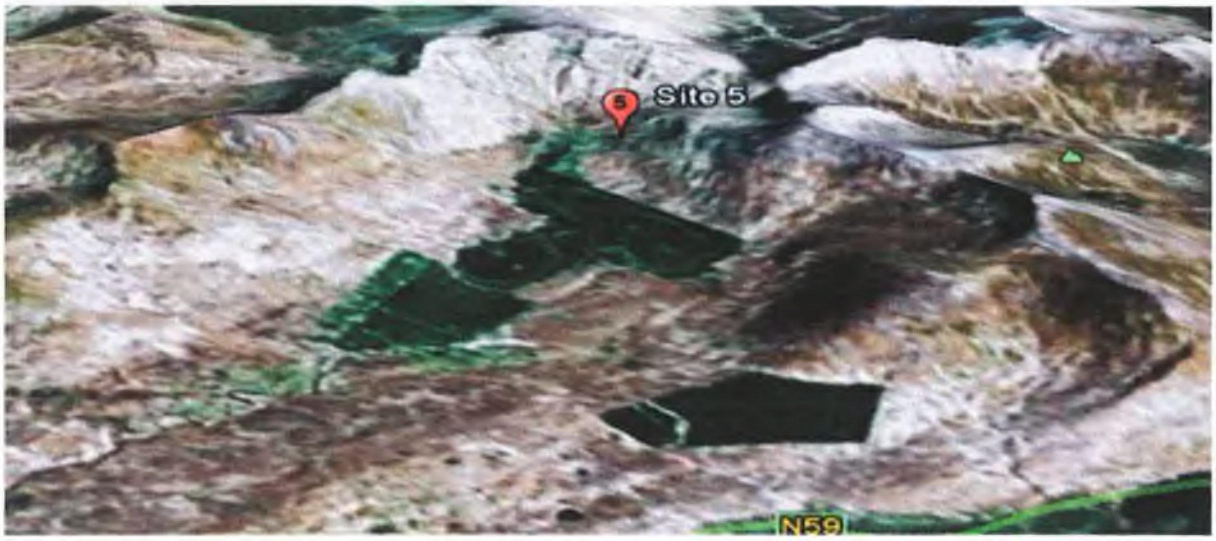


Figure 3.8: Site 5(Google Earth, n.d.)

3.5 Parameters

Once the five potential sites were selected, the next step of the site selection process required a scoring system to be drawn up of different parameters that were relevant in investigating the feasibility of a pumped storage system at each site. The scoring system would enable the most suitable site to be identified. Its structure was weighted in order to prioritise the most important elements of a pumped storage project. Therefore, to facilitate the weighted marking scheme, the scoring system was constructed of primary and secondary factors. The parameters selected as primary factors were chosen due to the effect on the technical aspect of the project. The primary factors that were selected are as follows:

- Topography
- Head
- Distance from sea
- Generating Capacity
- Accessibility
- Grid Connection

Topography is defined as "the shape or configuration of the land" (Michigan Department of Technology, Department & Budget, 2010). Therefore, topography was deemed to be a Primary Factor in the site selection process as the requirement for a seawater pumped storage system is a U-shaped valley or similar to act as the pumped storage system's higher reservoir (Spirit of Ireland, 2009a). With regards Head being chosen as a Primary Factor, it is outlined by Hamill (2001), that the factor is a fundamental element of pumped storage systems which enables the turbines to be activated.

The setup of this particular pumped storage system will require the penstocks to be installed between the higher reservoir in the selected valley and the lower reservoir's seawater, as seen in conventional pumped storage systems (Figure 2.1). Minimising the length of these penstocks will contribute to an overall efficiency rating of the system. This is due to "the head loss for fluid flow is directly proportional to the length of the pipe" (Moore, 2004). Therefore, the distance from the reservoir to the turbine is important. In addition, the distance from the sea to the higher reservoir is an important element when it comes to energy loss. Further to this, the generating capacity is also included as a primary factor.

From a feasibility of construction point of view, ease of access and egress to the selected sites will be an important aspect during the construction works (Bureau of Labour Statistics, 2009). The final Primary Factor is Grid Connection where the optimum means of grid connection will be analysed in co-ordinance with EirGrid's Grid25 strategy.

A maximum of 10 points can be awarded to Primary Factors (higher points awarded to most preferable site).

The direction of the Secondary Factors was focused on the impact on the social pillar of sustainability. These factors are:

- Land Use
- Social Setting
- Landscape

These elements are included in the marking scheme as it is accepted that the construction of a pumped storage system will impact the aforementioned parameters (Asian Development Bank, 2001). Therefore, it is desired to minimise these effects through the selection of the optimum site for the project.

A maximum of 8 points is allocated for Secondary Factors (higher points awarded to most preferable site).

Awarded points will be tabulated to identify the most suitable site in ∫3.6.

3.5.1 Topography

Favourable topography is a prerequisite requirement to initiate planning procedures of a pumped storage system (Deane et al., 2010). The purpose of including this parameter is to locate the valley which embodies maximum natural enclosure from the valley walls. In other words, minimising the requirement for dam construction is the ideal scenario. Dams are to be erected at the open end of the valley however some valleys may require additional structural reinforcement at different areas of the valley walls. An ideal valley would possess a flat base to facilitate larger storage capability. The following is an analysis of the topography of the selected sites and description how the selected sites compare to the outlined template.

Utilising Site 1 as a pumped storage system higher reservoir would entail a high degree of construction work to be carried out. The valley consists of two hanging valleys joining above the lake while the lakes existence creates a difficulty in establishing the nature of the valleys floor. Topographically, this valley embodies the ability to act as 50% of enclosure required of a higher reservoir in a pumped storage system- i.e. full enclosure on the north-west side of the valley while the sloping sides of the south-west/north-east elevations will require additional enclosure. Dam construction will be required parallel to the hanging valley on the south-east side of the valley.

Similarly, Site 2 consists of a number of hanging valleys. This north facing valley possesses the ability of full enclosure on the south-side of the valley while the east and west facing elevations slope downwards, which will require dam construction to for full enclosure. The valley's open face is on the north side which will require dam construction along to enclose this section. Again, this valley provides approximately 50% of the enclosure required for the pumped storage system higher reservoir. This valley possesses a flatter base which will facilitate greater storage capacity than previously seen in Site 1.

Site 3 possesses extremely favourable topography. The north, east and west sides of the valley are completely enclosed leaving only the open end of the valley to be enclosed. Further to this, the flat valley floor provides opportunity to greater storage capabilities. The only drawback of this site is the fact that the areas of the valley where differences in height are evident which may require reinforcing dam construction.

The topography of Site 4 is also extremely favourable for facilitating a higher reservoir construction project. The north, south and west sides of the site facilitate a full enclosure, however the height of the south valley side is considerably lower than the north valley side. Depending on the setup of the higher reservoir on the site, this may require dam construction to reinforce the enclosure capability of this side. Otherwise, the only dam construction that will be required is on the east facing open end of the valley. This valleys floor is narrower that Site 3's which justifies its slightly lower score (see Table 3.3).

The topography of Site 5 requires the open face of the valley to be enclosed. There are a number of hanging valleys in the east valley side which will provide further storage capacity. Effectively, the site consists of only two valley sides which join- giving the valley a V-shape when looking at the plan view. Due to this the site is deemed inferior-in terms of topography- than Site 3 which possesses a large open area. Other than this minor detail, the valley possesses a wide open area towards the open-end of the valley.

Considering these elements, the following points were awarded to the relevant sites:

Site	Points
Site 1	6
Site 2	6.5
Site 3	9
Site 4	8.5
Site 5	8.5

Table 3.3: Topography Scores

3.5.2 Head

Bryan (2009) reports that 'the ideal operating head' for pumped storage systems is between 500 and 700m. However, in the same article, Bryan outlines that a head of 400m would suffice for a pumped storage system. Therefore, to gain the full 10 points allocated for this parameter, sites head should be 400m or above. The marking scheme is as follows:

Head Recorded	Points Awarded
≥400m	10
350-399m	9
300-349m	8
250-299m	7
200-249m	6
150-199m	5
<150m	4

Table 3.4: Head Marking Scheme

The following sections outline the head of the selected sites and the scores awarded.

With regards Site 1, the existence of Lough Acorrymore in this valley makes it difficult to ascertain the topography of the valley base but also to ascertain the height of the lowest point of the valley. However, Ordnance Survey Ireland's 'Discovery Series' map number 30 (n.d.) outlines that Lough Accrrymore's height is 187m above sea-level. Similarly, the presence of Lakes in the valley at Site 2 makes it difficult to ascertain the true head of the site. However, in the same aforementioned mapping series, it is interpreted that Lough Laur is the lowest point of the valley at 178m above sea-level.

Again, Ordnance Survey Ireland's 'Discovery Series' map number 30 (n.d.) was utilised to ascertain the head of Site 3. The map indicates a head of 116m for this site. From the Ordnance Survey Ireland's 'Discovery Series' map number 37 (n.d.), the lowest point of Site 4 was deemed to be 190m. From the same map, the head of Site 5 was deemed to be 170m. The following is a synopsis of these parameters results:

Site	Head	Points
Site 1	187m	5
Site 2	178m	5
Site 3	116m	4
Site 4	190m	5
Site 5	170m	5

Table 3.5: Head Score

3.5.3 Distance

For this project, penstocks will be required to be installed underground to facilitate the flow of water from reservoir to ocean and vice versa. Head losses in these pipes will be proportional to the distance of these penstocks (Pacific Pump & Power, 2008). Therefore, maximising efficiency will entail selecting a site as close to the lower reservoir (the Ocean) as possible. The Spirit of Ireland initiative have outlined that suitable valleys for the groups proposed pumped storage system are 1-2km from the sea (Spirit of Ireland, 2009a). This distance will act as a template for the marking scheme for this parameter. The marking scheme is as follows:

Distance Recorded	Points Awarded
<2km	10
2-4km	8
4-6km	6
6-8km	4
>8km	2

Table 3.6: Distance Marking Scheme

To ascertain accurate figures, it was important to establish an intake point for each site, which was decided as the lowest point of each valley. Distances were recorded by utilising Survey Ireland's 'Discovery Series' map numbers 30 and 37 (n.d.; n.d.).

Site	Distance	Points
Site 1	2.3km	8
Site 2	2.9km	8
Site 3	2.75km	8
Site 4	1.8km	10
Site 5	6.5km	4

Table 3.7: Distances to Sea

However, the location of the intake pipe will be at an area approximately 500m from the shoreline and at a depth of 600m similar to works carried out at Sahl Hasheesh in Egypt

(Elsafty & Saeid, 2009). Locating the intake pipe at this point will enable the fluctuations of tides in the sea to be overcome.

3.5.4 Generating Capacity

The rated generating capacity of each site is an important element of the site selection process as it determines the output power of the pumped storage system. The following marking scheme was formulated for this parameter:

Output (MW)	Points Awarded
≥ 1500	10
1200-1499	9
1000-1199	8
800-999	6
600-799	5
400-599	4
≤399	3

Table 3.8: Generating Capacity Marking Scheme

The generating capacity is calculated as:

$$P_{ow} = \eta . \rho . g . h . Q$$

Where:

P_{ow} = rated generating power
ρ = density of water (kg/m^3)
g = gravitation constant (m/s^2)
Q = rated generating flow (m^3/s)
h = rated generating head (m)
η = efficiency (taken as 0.90)

The density of water was taken as $1000kg/m^3$, while the gravitation constant was taken as $9.81\ m/s^2$. The static head was previously calculated for each site in ∫3.5.2. However, to determine the flow rate for each site, the capacity of each site was divided by a selected flow rate. An example of this calculation is illustrated as:

Site 1:

Say $Q = 50m^3/s$

$\therefore (225 \times 10^6\ m^3) / (50m^3/s) \quad = 4 \times 10^6$ seconds

4×10^6 seconds/ 3600 $\quad$ = 1111 hrs (46 days)

Essentially this means that it would take 46 days for the higher reservoir at Site 1 to empty which was deemed to be excessive for cycle duration, especially when considering the information illustrated in Figure 3.9 (McKeogh, 2007). It highlights the Ireland's peak demands and how a pumped storage system can provide for said loads. It indicates that these peak loads are at 9.30am - 2.00pm and from 5.00pm – 8.00pm. To provide for these loads a pumping period of 5.5 hours is required to refill the released water during the peak load. It is anticipated that this 5.5 hour period may need to be extended due to extra demands from interconnectors. However, the 46 day period provides scope to increase the flow rate to provide for these peak demands and interconnectors. Therefore, a flow rate of $390m^3/s$ can be utilised for each site (as calculations deemed emptying periods of all sites excessive) to ascertain each site's generating capacity. This flow rate is identical to the exemplary Dinorwig pumped storage system which is one of the world's largest pumped storage systems.

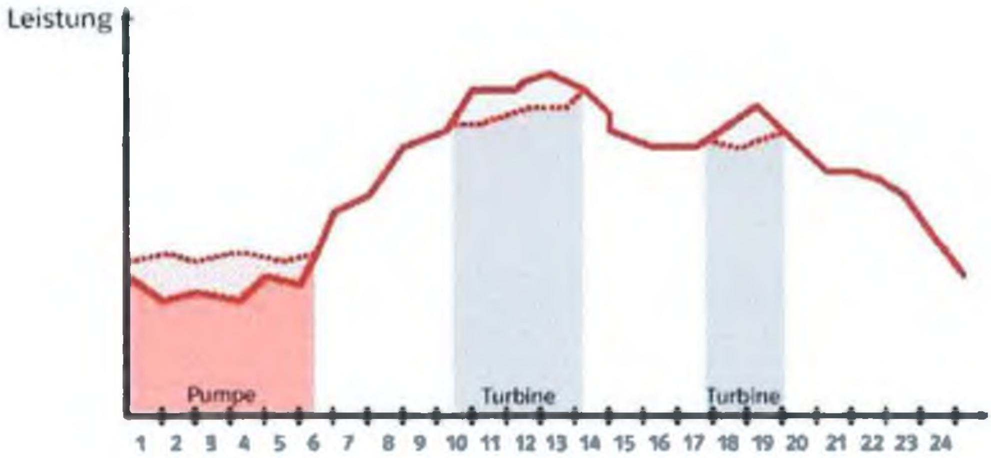


Figure 3.9: Peak Loads & Pumped Storage (McKeogh, 2007)

To integrate head loss into the generating capacity equation, an estimate of 5% was made for the factor. Therefore, the recorded head in ∫3.5.2 will be reduced by 5% when integrated into the equation. This is where pumped storage systems as net consumers of energy comes in as for pumping the estimate of 5% would have been added to head. The generating capacity of each site is calculated as follows:

Site 1:

$P_{ow} = \eta.\ \rho.\ g.\ h.\ Q$

$= (.9)\ (1000kg/m^3)\ (9.81\ m/s^2)\ (178m)\ (390m^3/s)$

$= 612{,}909kW$

$= 613MW$

Site 2:

$P_{ow} = \eta.\ \rho.\ g.\ h.\ Q$

$= (.9)\ (1000kg/m^3)\ (9.81\ m/s^2)\ (169m)\ (390m^3/s)$

$= 581{,}919kW$

$= 582MW$

Site 3:

$P_{ow} = \eta.\ \rho.\ g.\ h.\ Q$

$= (.9)\ (1000kg/m^3)\ (9.81\ m/s^2)\ (110m)\ (390m^3/s)$

$= 378{,}764kW$

$= 379MW$

Site 4:

$P_{ow} = \eta.\ \rho.\ g.\ h.\ Q$

$= (.9)\ (1000kg/m^3)\ (9.81\ m/s^2)\ (180m)\ (390m^3/s)$

$= 619{,}795kW$

$= 620MW$

Site 5:

$P_{ow} = \eta.\ \rho.\ g.\ h.\ Q$

$= (.9)\ (1000kg/m^3)\ (9.81\ m/s^2)\ (161m)\ (390m^3/s)$

$= 554{,}372kW$

$= 554MW$

These outputs and awarded points are tabulated in Table 3.9:

Site	Output (MW)	Points
Site 1	613	5
Site 2	582	4
Site 3	379	3
Site 4	620	5
Site 5	554	4

Table 3.9: Site Outputs

As can be seen from these results, it each individual site does not possess enough generating capacity to be considered as large scale. However, constructing pumped storage systems at a number of these sites can provide the desired 1500MW for this project.

The 390 m^3/s flow rate ensures that water will leave the higher reservoir at a comparatively higher rate than other reservoirs. The hourly West of Ireland wind speeds in Figure 3.10 indicates high wind speeds during the early hours which correspond with the pumping period illustrated in Figure 3.9. The intermittency of the wind, as evident in Figure 3.10, will inevitably lead to occasions where there is not enough wind to pump the water during this time. Therefore, to eliminate this risk, the design of the pumped storage system will incorporate power from conventional generation plants to be used only when necessary.

The data from Figure 3.10 raises an issue over the high wind speed during the 5.00pm - 8.00pm peak demand. The use of reversible pump turbines, which are commonly utilised, would be ineffective as these high wind speeds cannot be utilised to pump the water while the machine is acting as a turbine. Therefore, the use of separate pumps and turbines are suggested. In periods of high wind speeds, there is also the option to connect the winds power directly to the electrical grid which will eliminate efficiency losses.

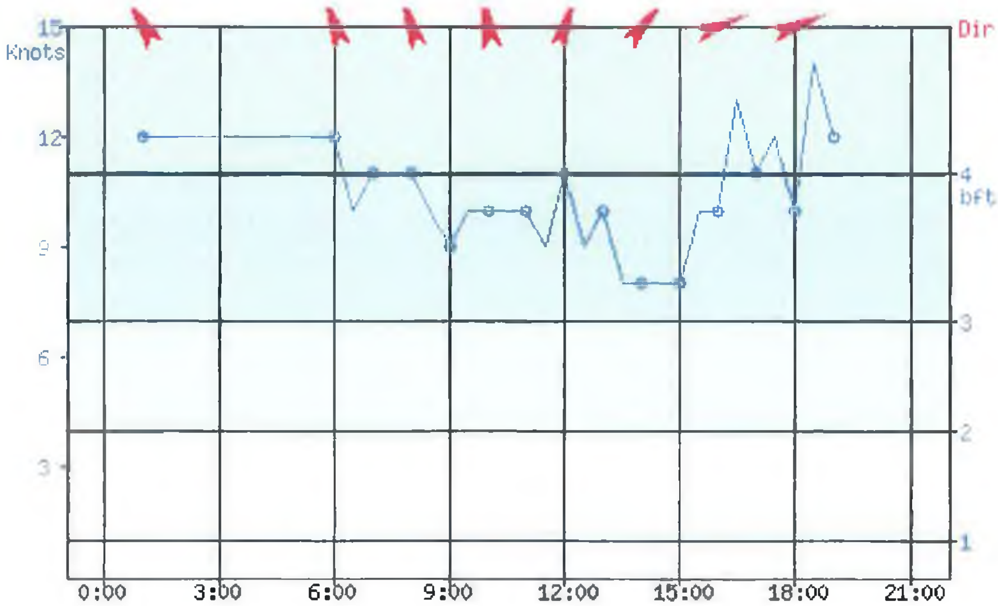


Figure 3.10: West of Ireland Wind Speeds (Wind Finder, 2010d)

The amount of wind energy that can be harnessed for pumping can be estimated by analysing the current 14.4% renewable penetration figure. Considering that in excess of 150MW installed wind capacity within Mayo, Galway and Sligo (IWEA, 2010), it can be estimated that future 60% renewable penetration will require 600MW installed wind capacity within these counties. This extrapolated figure is in the correct region for the outputs of each of the individual sites. However, connecting a number of these sites to the electrical grid will require increased wind penetration. Otherwise, power from existing conventional generation plants will be used extensively which would not be beneficial for achieving renewable energy targets.

3.5.5 Accessibility

To determine the marking scheme for the accessibility segment of the scoring system, it was necessary to study the status of the existing roads surrounding the sites. As all of the selected sites are located in rural areas which ensured that the need to integrate Motorways, Dual Carriageways and Primary Roads into the marking scheme was eliminated. Therefore, the following marking scheme was formulated:

Road Class	Points Awarded
Site accessible via National Secondary Rd.	10
Site accessible via Regional Rd.	8
Site Accessible via Third Class Rd.	6
Inferior Rds.	4

Table 3.10: Accessibility Marking Scheme

Ordnance Survey Ireland's 'Discovery Series' map number 30 and 37 (n.d.; n.d.) were utilised in combination with Ordnance Survey Ireland's map viewer (n.d.) for this study. Awarded marks are subject to adjustment depending on the distance of the site from the road and any combination with 'Tracks' or 'Other Roads'.

Site 1 is accessible via the R319- a regional road, illustrated in Figure 3.11- which runs through Achill Island. Under the terms of the marking scheme, the presence of a road of this class in the area would merit 8 points being awarded. However, the existence of a passageway, termed 'other road' in Ordnance Survey Ireland's 'Discovery Series' map number 30 (n.d.), ensures that a maximum 10 points are awarded to this site as vehicles can gain direct access to the site. There are no other feasible means of access to the site.

Figure 3.11: Access to Site 1 (Ordnance Survey Ireland, n.d.)

Figure 3.12 illustrates the most feasible means of access to Site 2. The Third Class Road, represented by the yellow road in Figure 3.12, runs to the West, South and South-East of the site while the aforementioned R319 runs to the sites North and North-East. The proposed route is to direct vehicles along the Third Class Road where a track, (illustrated in Ordnance Survey Ireland's 'Discovery Series' map number 30), can direct vehicles relatively close to the site- where the site setup should facilitate an appropriate means of access to the site itself. In terms of egress, there is an option to continue along the aforementioned broken line which will gain access to the R319 of alternatively, vehicle can be redirected out onto the Third Class Road via the same track utilised in accessing the site. Under the terms of the marking scheme, 6 marks are to be awarded to sites accessible via a Third Class Road. However, the track eliminates the requirement to construct a new means of access to the site in the sense that contractors can improve the condition of this track. Therefore, 7 marks are awarded for this aspect of this site.

Figure 3.12: Access to Site 2 (Ordnance Survey Ireland, n.d.)

Figure 3.13 illustrates Site 3 as outlined in Ordnance Survey Ireland's map viewer (n.d.). The site is accessible via the N59, represented by the green and white road to the south of the site. A passageway, termed 'other road' which will gain access to tracks which will provide access into the valley as outlined in Ordnance Survey Ireland's 'Discovery Series' map number 30 (n.d.). As the site is accessible via the National Secondary Road a full 10 marks should be awarded for this aspect. However, as the National Secondary Road only provides access to within 2km of the open end of the valley. Therefore, two points are deducted. However, a further point is awarded for the access provided by both the 'other road' and the track which brings the tally awarded back to the maximum 10 points.

Figure 3.13: Access for Site 3

The most feasible means of access to Site 4 (Figure 3.14) is via the R335 which is to the east of the site. There are tracks and 'other roads' in-situ at the open end of the valley; however-unlike similar roadways in Site 3- these do not facilitate access into the valley. Therefore, 8 marks are awarded as the site is accessible via a Regional Road. This road only provides access to within 1km of the valley entrance which justifies one point being deducted. Therefore, prior to construction work on this site a new access route must be constructed.

Figure 3.14: Access to Site 4

Access to Site 5 (Figure 3.15) will be by means of utilising the National Secondary Road (N59) to the south of the site. From here, vehicle can access the site via the Third Class Road which will gain access to the open end of the valley and essentially to the site entrance. Accessing the site via the National Secondary Road justifies 8 points being awarded for this aspect. Further to this, as the site is further accessible via a Third Class Road, a maximum 10 points is awarded for this parameter.

Figure 3.15: Access to Site 5 (Ordnance Survey Ireland, n.d.)

The following figure tabulates the points awarded for this parameter.

Site	Points
Site 1	10
Site 2	7
Site 3	10
Site 4	7
Site 5	10

Table 3.11: Accessibility Score

3.5.6 Grid Connection

Central to the feasibility of a West of Ireland pumped storage system will be the ability of Ireland's electrical grid to transmit the power around the country. The revamping of the existing electical grid will be discussed in Chapter 4, however the suggested means of grid connection at this point is to establish a 400kV line from each site to Rush North Beach, Co. Dublin- which is the location of the East-West interconnector (EirGrid, 2008b) - to facilitate power transmission and exporting. Therefore, to allocate scores for this parameter, the issue that is being analysed is the shortest distance from the selected sites to Rush North Beach, Co. Dublin. EirGrid have allowed for 800km for extra high voltage transmission lines (≥220kV) with 400kV outlined to be installed from the Dublin grid to the Belfast grid. This length of this line is estimated to be in the 120km region. Therefore, another 680km of extra high voltage transmission lines is allowed for. With this under consideration, the following marking scheme was drawn up for this parameter:

Distance Recorded	Points Awarded
<100km	10
100-199km	8
200-299km	6
300-399km	4
400-499km	3
500-599km	2
600-680km	1
>681km	0

Table 3.12: Distance Marking Scheme

Google Earth was utilised to calculate the distances. The results are tabulated below:

Site	Distance	Points
Site 1	273.5km	6
Site 2	253km	6
Site 3	239.6km	6
Site 4	243km	6
Site 5	251.5km	6

Table 3.13: Grid Connection Distances

Grid Connection will be discussed in further detail in Chapter 4.

3.5.7 Land Cover

How the land is utilised in the areas of the selected sites is an integral element in mitigating the effects of the pumped storage system on the surrounding inhabitants. Ideally, the construction of the pumped storage system should be in areas of land on 'low importance', i.e. where land is not used for Agricultural, Forestry or similar purposes. Furthermore, the construction and resultant operation of the pumped storage system should have minimum impact on its surroundings. With this in mind, the following marking scheme was formulated.

Land Use	Points Awarded	Preference
Peat Bog	8	Most Preferable
Areas of Vegetation	6	
Forestry	4	
Agriculture	2	Least Preferable

Table 3.14: Land Use Marking Scheme

Peat Bog Areas are the most preferable as such areas are of marginal use for farming and the land covers widespread areas in Galway and Mayo. With regards the 6 points awarded for sites located in vegetation areas, it is accepted that vegetation should be preserved (Collier County, 2009) however; it is deemed there are more pressing issues in agriculture and forestry in this instance. As forestry land cover in Ireland is only 12.6% (EPA, 2010)- which stands as one of Europe's lowest tree cover portions (EPA, 2006) it was felt that if possible, these areas should be avoided as it forests have a role to play in limiting carbon emissions (EPA, 2006). Finally, due to the importance of agriculture with regards employment and exporting (Teagasc, 2010), it was decided that 2 points are awarded for sites located within agriculture land cover.

Depicted in Figure 3.16 is a section of the Co. Mayo Corine Land Cover. From the visual, the land types are attainable. With regards Site 1, it is evident that the predominant land type in the area is Peat Bog, which merits a maximum 8 points, while there is evidence of a beach to the south of the site which may be affected by the laying of penstocks from the higher reservoir to the Ocean. However, as there are alternative beaches on the island, the award of the full 8 points for this site is not compromised.

Similarly, the principal land cover at Site 2 is Peat Bog. However, the presence of a Coniferous Forest to the north of the site- at the open end of the valley- mitigates the suitability of this site in this instance. Therefore, it is required to reduce the points awarded from the maximum 8 points to a compromised mark of 6. A hybrid of land cover is again evident in the case of Site 3 at Carheenbrack. At the open end of the valley- where the site is accessible- it is apparent that Arable Land is present which represents agricultural practices. However, the land at the valley itself is currently covered by Coniferous Forest and Arable land. The land cover and its anticipated uses in the agricultural and forestry industries indicate that this particular site is not the most suitable for a pumped storage system in this respect. With these elements taken into account, a compromised mark of 3 was awarded.

Again fusion of land cover is apparent for Site 4 at Killary Harbour. The valleys floor is covered by Arable Land and while a large segment of the fjord is covered by bare rock. The bare rock is ideal for this pumped storage system as the use of the land for other purpose is minimal. The presence of the rock merits 8 marks being awarded for this site; however the site suitability is mitigated by the existence of the Arable land. Therefore, a compromise is to be reached in the award of the points therefore, 5 marks are awarded for this site.

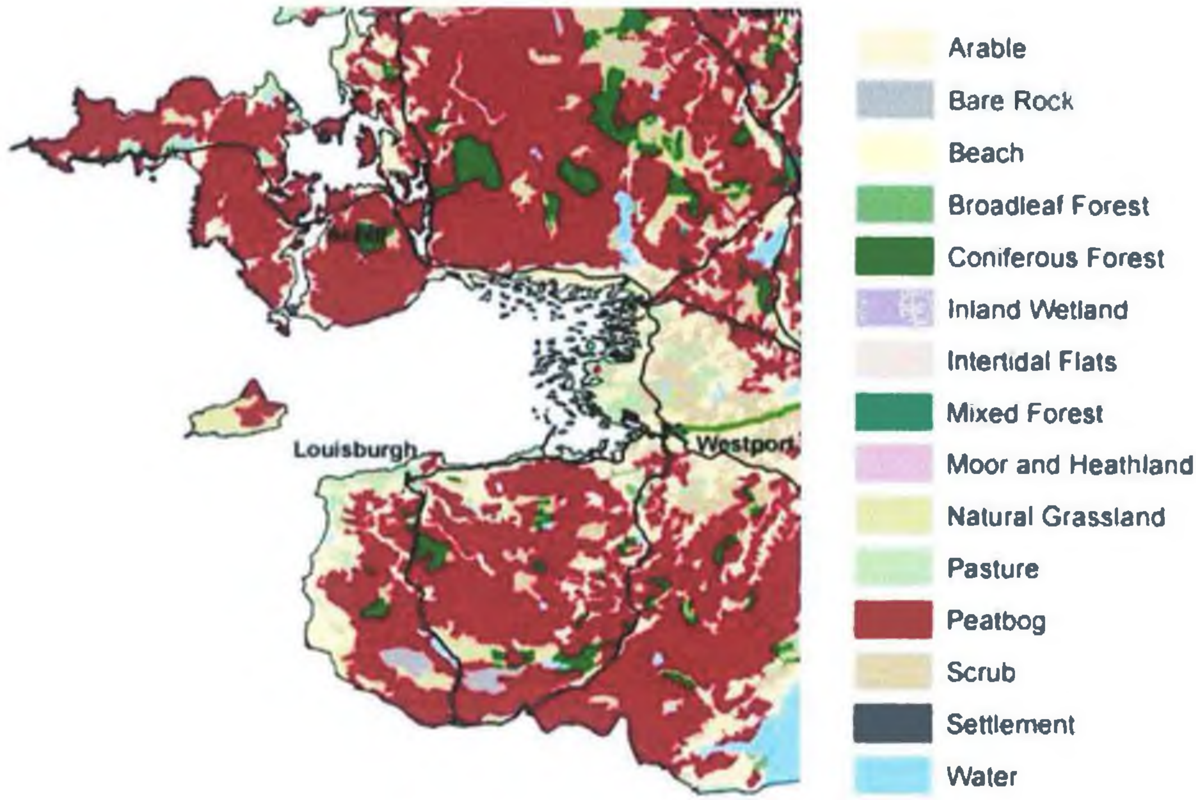


Figure 3.16: Mayo Land Cover (Mayo County Council, 2008b)

Figure 3.17 illustrates the Corine land cover of Galway (Galway County Council, 2009). From this, it can be seen that the predominant land cover for the West of Galway consists of Peat Bog cover. Whilst studying Site 5's land cover, it is evident that the site is located within an areas consisting of Peat Bog and Open Space/Sparse Vegetation. Construction of the pumped storage system on this particular site should facilitate, as much as is reasonably possible, the preservation of the vegetation. Due to a combination of land cover in this site, a compromised mark of 7 points was awarded for this site.

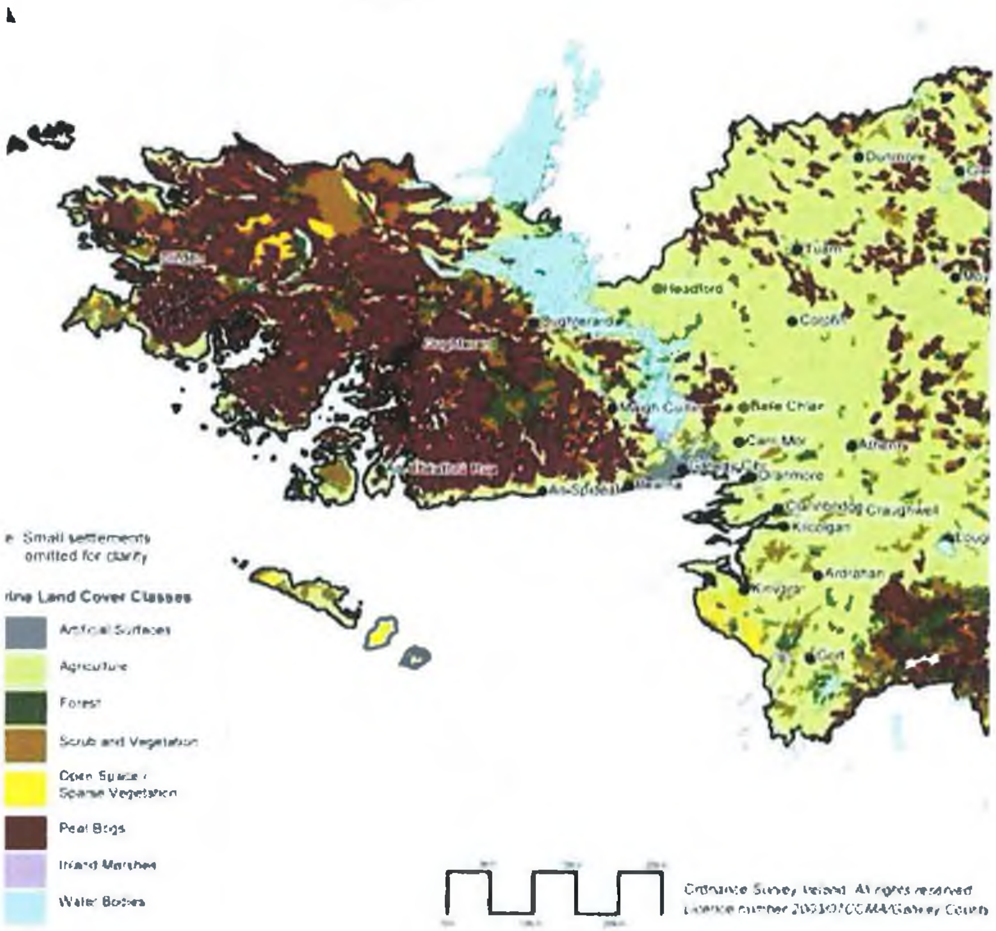


Figure 3.17: Galway Land Cover (Galway County Council, 2009)

The results for this parameter are tabulated below:

Site	Points
Site 1	8
Site 2	6
Site 3	3
Site 4	5
Site 5	7

Table 3.15: Land Use Score

3.5.8 Social Setting

The social impact of the construction of a pumped storage system is required to be studied when attempting to ascertain the feasibility of such a project *(Hydro4Africa, 2010)*. To determine accurate scores for this element of the scoring system, the following will be investigated with regards to each individual site:

- Population
- Housing

The population in the area was deemed to be included as it is desired to minimise the quantity of individuals affected by the works. Following on from this, the issue of housing enters the equation as any existing housing in the valley will require demolition prior to flooding. To determine the marking scheme for this parameter, population and housing were marked individually with the awarded marks being the average score for each site. The following table indicates the template utilised for this marking scheme.

Population	Score	Houses Demolished	Score2	Preference
≤ 600	8	0	8	Most preferable
601-1200	6	1-5	6	
1201-1800	4	6-10	4	
≥ 1801	2	≥ 11	2	Least preferable

Table 3.16: Social Setting Marking Scheme

Ordnance Survey Ireland's map viewer was utilised to identify any houses which require demolition.

Site 1 is located at Keel, on the Western tip of Achill Island. The population of Keel itself was not attainable; however the population of Achill Island as a whole is 2700. It is accepted that a large proportion of this population is not reside in the Keel area. However, as the site is located on the most Westerly section of the island, all traffic to the site must be directed through the Island which will affect a large portion of this population. Additionally, studies of the OSI online digital mapping detected that one building will be required to be demolished as it is deemed to be inside the boundaries of the higher reservoir. There are a number of houses to the south of the site which will be receptors of disruption throughout the course of the construction works; however it is not anticipated that these houses will be required to be demolished.

With regard to Site 2, the area's population was not attainable, however; the site location is addressed as Achill. Therefore, it was adjudicated that the Achill's environs would be similar to the island's population of 2700. Again, it is estimated that a large portion of these individuals will not be heavy receptors of the projects works. In addition, no buildings will be required to be demolished on this site. The solitary sets of houses is located to the West of the site and are merely deemed to be heavy receptors to effects of the projects work such as excessive, sustained heavy traffic, and dust arisings etc.

The population of the environs of Newport- the closest town to Site 3- is outlined to be 1,736, which is a reduced figure to the populations dealt with at Sites 1 & 2. Again, there are no buildings that require at this site. 3 buildings are situated at the open end of the valley which will be extremely heavy receptors to the affects of the works.

No direct population was attainable for the Delphi area- the area of which Site 4 is located. The closest location that a population was attainable was Louisburgh, whose environs population stands at 755, which is significantly lower than population rates of environs surrounding of previous sites. Again, there is no requirement to demolish houses in the area; however, 3 houses are located at the open end of the valley which will be heavy receptors to the affects of the works.

With regard to Site 5, the population of the Clifden environs is outlined to be 1,929 which is a similar figure to the population of Site 3. Whilst studying the OSI online digital mapping, it was discovered that there were a number of buildings- located at the open end of the valley- that will be extremely heavy receptors to the affects of the works. Also, there are a large number of residencies to the south of the site that will also be disrupted by the works.

With these details taken into account, the following scores were formulated:

Site	Score
Site 1	4
Site 2	5
Site 3	6
Site 4	7
Site 5	5

Table 3.17: Social Setting Score

3.5.9 Landscape

As landscape is a precious national asset (Galway County Council, 2009) it is desired that the construction of a pumped storage system should not interfere with visual beauty of the area of construction. Both the Galway and Mayo County Councils have established the scenic views within their area (Galway County Council, 2009; Mayo County Council, 2008b). Similar to the protected areas, proposed developments in such areas are to be assessed by the Councils. With regard to the marking scheme for this particular element of the scoring system, the following was formulated.

Views	Points Awarded	Preference
No Significance	8	Most preferable
Scenic Views	4	
Highly Scenic Views	2	Least Preferable

Table 3.18: Landscape Marking Scheme

The scenic views map provided by the Mayo County Council (see appendix) outlines the scenic views in Co. Mayo. From this map, it is attainable that Site 1 is situated adjacent to a scenic route and a highly scenic view. In addition, it is illustrated that the site itself is an element of a scenic view. Similar readings occur in the case of Site 2 whereby the seaward part of the site is a component of a scenic view. To the south of the site are a scenic route and a highly scenic view which are not expected to be majorly affected by the works. With regards Site 3, studies of the scenic view map deem the site to be highly scenic. Site 4 is also the subject of a highly scenic view.

Whilst studying the "Focal Points/Views" map provided by the Galway County Council (2009) (see appendix), it was discovered that Site 5 is entailed in a highly scenic view due to its position within the Twelve Pins. The Galway County Council also provide mapping outlining the landscape values and the landscape sensitivity of the county. From these, it is found that Site 5 located in areas of outstanding landscape value. This means that communities hold the area in high regard (Galway County Council, 2009) so therefore, development of a pumped storage system within these areas may be met with public resistance. With regard to landscape sensitivity, it was discovered that Site 5 is classed as

"Unique Landscape Sensitivity". Therefore, scope for accommodating a project in these areas without adversely affecting the landscape value is minimal. With this taken into account the following points were awarded for this section.

Site	Points
Site 1	4
Site 2	4
Site 3	2
Site 4	2
Site 5	2

Table 3.19: Landscape Score

3.6 Scoring Card

The following table compiles all awarded scores for each site:

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5
Primary Factors					
Topography (10)	6	6.5	9	8.5	8.5
Head (10)	5	5	4	5	5
Distance (10)	8	8	8	10	4
Capacity (10)	5	4	3	5	4
Accessibility (10)	10	7	10	7	10
Grid Connection (10)	6	6	6	6	6
Secondary Factors					
Land Use (8)	8	6	3	5	7
Social Setting (8)	4	5	6	7	5
Landscape (8)	4	4	2	2	2
TOTAL:	56	51.5	51	55.5	51.5

Table 3.20: Scoring Card

From the awarded points from the critical analysis of each site, the most suitable site of the selected sites for the pumped storage system is Site 1. The feasibility of a pumped storage system at Site 4 is marginally lower. Site 2 is deemed to be the third most feasible site as it possesses a higher generating capacity that Site 5, whilst Site 3 is the least feasible of the five selected sites.

3.7 Ecological Setting

The fundamental role of protected sites is to conserve important and valuable habitats (Galway County Council, 2009). Protected sites refer to Special Ares of Conservation (SACs), National Heritage Areas (NHAs), and Special Protection Areas (SPAs), and are outlined by the National Parks and Wildlife Service (Galway County Council, 2009). Descriptions of these sites are as follows:

- **SACs** are protected areas which habitat "plants and animals species that are rare or threatened in Europe" (Galway County Council, 2009).
- **SPAs** are designated to protect and conserve rare and/or threatened bird species (Galway County Council, 2009).
- **NHAs** are outlined as the areas which "cover nationally important semi-natural and natural habitats, landforms or geomorphilogical features, wild plant and animal species or a diversity of these natural attributes" (Galway County Council, 2009).

Illustrated in Figure 3.18 & Figure 3.19 are visuals of the protected sites within Co. Mayo and Co. Galway. As can be interpreted from these images, each of the selected sites are located in protected areas.

Figure 3.18: Mayo Protected Areas (Mayo County Council, 2008b)

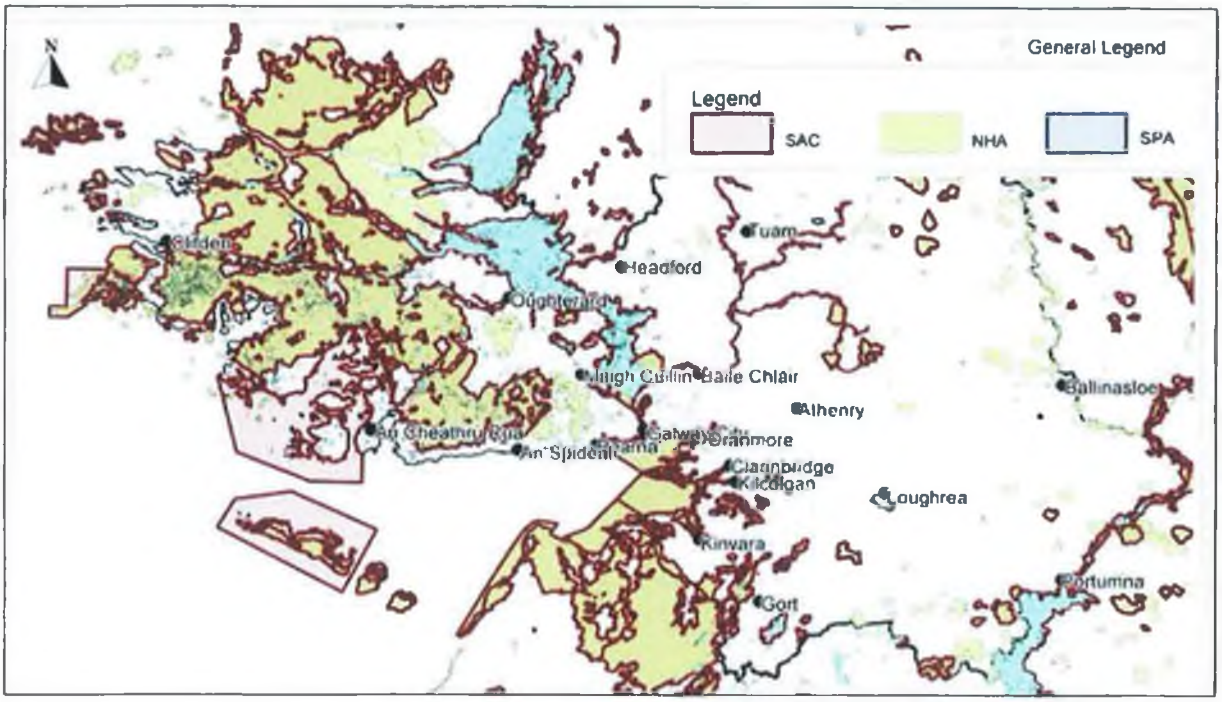


Figure 3.19: Galway Protected Sites (Galway County Council, 2009)

The following table outlines the whether or not the selected sites are within the boundaries of protected areas:

Site	SACs	NHAs	SPAs
Site 1	✓	✓	
Site 2	✓	✓	
Site 3	✓		
Site 4	✓	✓	
Site 5	✓	✓	

Table 3.21: Sites and the Protected Areas

Furthermore, the National Parks & Wildlife Service map viewer indicate that all sites are located in Proposed Special Protection Areas.

Mitigating the effects of the construction of the pumped storage system on the surrounding ecology and obtaining planning permission will require proposals to local authorities, Department of Environment, Heritage and Local Government and if necessary An Bord

Pleanála. In compliance with The Planning and Development Act 2000, Local Authorities should possess a Development Plan for the jurisdiction through which planning applications will be analysed (National Parks and Wildlife Service, 2008a). As this pumped storage is a large scale project, an Environmental Impact Assessment will be required for planning permission to be granted (National Parks and Wildlife Service, 2008a). Furthermore, it is likely that planning application will be referred to the Minister for the Environment, Heritage and Local Government as the author anticipates that the project will have "significant effects in relation to nature conservation" (National Parks and Wildlife Service, 2008b). Post Development Applications Unit analysis it may be requested by the Department of Environment, Heritage and Local Government or the Department may advise that special conditions should be included in the granting of planning permission (National Parks and Wildlife Service, 2008a). Where 'significant negative impacts on nature conservation may not be mitigated' the Department may advise the disapproval of planning permission, although is outlined to be an 'extreme' measure (National Parks and Wildlife Service, 2008a). Refusal of planning permission can be appealed to An Bord Pleanála who investigates appeals in an "open and impartial" manner.

For a project of this nature to be granted planning permission, it will be the duty of the relevant Local Authorities to "subject any plan to an Appropriate Assessment" where the authorisation of projects will depend on the nature of the affect of the work on the natural environment *(Galway County Council, 2009)*. Further to this, development in SACs and SPAs must be in compliance with the outlined Management Plans for the protected areas *(Galway County Council, 2009)*.

The Corrib Gas Field Development is relevant to this project due to its role in energy supply and its requirement of pipeline development in protected areas (Independent Media Centre Ireland, 2010). Obtaining planning permission for the gas line required a plan of development to be formulated which will include "the reasons behind the selection of the appropriate development option, and a comprehensive and technical outline of the project and how it would operate" (Department of Communications, Energy and Natural Resources, 2010b). The application for pipeline construction required the formulation of an environmental impact statement. Conditions of the project required an Environmental

Monitoring Group to be set up. Planning applications for the Onshore Terminal of the project was approved after an appeal to An Bord Pleanála.

3.8 Conclusion

The main aim of the site selection process was to identify the most suitable site for a large scale pumped storage system. Ultimately, due to the low power output of each site, the process failed to identify a site suitable for a large scale pumped storage system; however the process enabled the author to recognise a variation of the original plan which will facilitate a large power output onto the electrical grid. This variation focuses on constructing three pumped storage systems which would facilitate in excess of 1500MW to be produced and would collectively act as a large scale project. The three sites in this setup are Site 1, Site 2 and Site 4 which contribute to an overall output of 1815MW. This setup will be the subject of investigations into the feasibility of grid connection in Chapter 4.

The research in this chapter highlights the West of Ireland as a location of excellent potential for developments within the energy sector. The integration of combined 1815MW pumped storage systems within the area would no doubt change the face of the existing market. Even constructing just one of the five selected sites would have a significant impact on the electrical grid. For example, if a pumped storage system was to constructed at Site 1 solely, its 613MW output would ensure the system would be considered to be in the same bracket as Moneypoint as one of the more significant plants in the country. Therefore, it may be prudent to construct one project at a time to identify the effect of its impact and establish how improvements can be made.

Chapter 4 – Grid Connection

4.1 Introduction

The electrical grid is an integral element to this project as it facilitates electricity transmission from the pumped storage systems. A 150% rise in demand over the past 20 years has occurred contemporary to a lack of investment in the electrical grid (EirGrid, 2008a). Ireland's TSO, EirGrid, have formulated a strategy, titled Grid25, to revamp the existing electrical grid to cope with these rise in demands. The purpose of this chapter is to investigate the problems with the existing electrical grid and to discover if the Grid25 strategy can facilitate the integration of the combination of West of Ireland pumped storage systems into the electrical grid.

4.2 The Existing Irish Electrical Grid

It is outlined by Eirgird that the existing Irish electrical grid is an amalgamation of "high voltage lines, cables, substations, and control and monitoring systems" (2006c) which facilitate the transmission of high class power from suppliers to the area of consumption. It is without doubt that the electrical grid provides a platform to assist the flow of electricity in a secure and reliable manner (EirGrid, 2006c), however, as alluded to in ∫1.4.1, the condition of the existing grid will not be capable of future large-scale penetration of renewable energy (Ruttledge, 2010). Further to this, the benefits of integrating pumped storage systems into the electrical grid are evident in information supplied from EirGrid. The source outlines that the "the system (electrical grid) is operated around the clock to balance supply and demand and to control flows of power on the network" (EirGrid, 2006c). The load balancing effect the pumped storage systems provide would greatly assist operations in this instance.

The existing Irish electrical grid's components consist of 400kV, 220kV and 110kV lines whilst 275kV lines are utilised in Northern Ireland. The 400kV and 220kV lines facilitate the transmission of high voltage around the country (EirGrid, 2008a). The electrical grid also entails in excess of 100 nodes which facilitate power reduction and distribution lines (EirGrid, 2006d). These distribution lines consist of 38kV, 20kV and 10kV lines (EirGrid, 2006d). From these lines, the power can be fed into a reduced voltage distribution system to serve domestic, commercial and industrial consumers or can be utilised by large industrial operations (Eirgird, 2006d). ESB act as the Distribution System Operator for the distribution grid. (Eirgird, 2006d).

The formation of the electrical grid is likened to a motorway network which transmits power from Ireland's electricity generating facilities. As previously mentioned in ʃ1.4.1, the solitary 400kV lines are installed between Moneypoint and Dublin (See Transition System Map attached in Appendix). Other large generation plant such as Tynagh's 384MW plant is served by a 220kV line which runs through the West and connects to the Northern Ireland Grid. The 220kV line also feeds directly to the most northerly 400kV line. With regards the country's largest cities, it can be seen from EirGrid's map that a hybrid of 220kV and 110kV lines serve both Cork and Dublin. In contrast, high voltage transmission in the West of Ireland leaves a lot to be desired. It can be seen that 220kV lines are directed to Galway city from Tynagh and from the Prospect 220kV station in Co. Clare. A series of 110kV lines serve the rest of the region. From this map, it is evident that the integration of West of Ireland pumped storage systems will require an update of the existing electrical grid. This opinion is reinforced when considering the high voltage transmission lines utilised in Japanese pumped storage systems, as discussed in ʃ1.4.1. In particular, an overhaul of the transmission infrastructure in the West is imperative to enable the pumped storage system to provide power to the entire country.

Figure 4.1 illustrates Ireland's installed wind capacity by county. The West coast of Ireland possesses a large installed capacity, with in excess of 150MW installed in the coastal Galway, Mayo and Sligo counties. Further to this, it is outlined by Melia (2010) that an additional 39 wind farms will be connected to the electrical grid within these counties by 2020. To facilitate these farms power, a stronger grid in the west will be required as currently the area is a weak point in the electrical grid (EirGrid, 2008a).

3.2 Total acreage of Athlone borough 1831-1901, including separate acreage totals for Athlone, Co. Westmeath and Athlone, Co. Roscommon.

3.3 Population proportions by religious denomination, Athlone town, Athlone Co. Westmeath and Athlone Co. Roscommon.

3.4 Population change by religious denomination in Athlone 1861-1901, Athlone, Co. Westmeath 1861-1901, Athlone, Co. Roscommon 1861-1901
Overall trend by religious denomination Athlone, Athlone Co. Westmeath and Athlone Co. Roscommon 1861-1901.

3.5 Proportion of Athlone's religious denominations by sex 1861-1901.

APPENDIX 4: POLITICS

4.1 MPs elected for Athlone Borough 1837-1885.

4.2 MPs elected for the constituencies of South Roscommon and South Westmeath 1885-1900.

APPENDIX 5: MISCELLANEOUS

5.1 Map of Athlone showing a number of important structures.

5.2 Additional photographs and images.

5.3 Information relating to Athlone Union Workhouse.

5.4 Census form used in the compilation of housing statistics.

Figure 4.1: Installed Wind Capacity by County (IWEA, 2010)

It is estimated by EirGrid (2008a) that overloading of certain areas of the electrical grid may occur within 5-10 years due to maximum capacity being reached. In essence, this issue will threaten security of supply (EirGrid, 2008a). In addition, economic growth within the country would be stunted as companies would be forced to locate to areas with high quality electrical grid infrastructure. Interestingly, EirGrid (2008a) also address the issue of low-cost electricity. It is stated that low-cost generators would not be able to connect to the grid, thus mitigating the competitiveness within the Irish electricity market. Given that this proposed project entails the supply of clean electricity, it becomes clear such a project can be beneficial for the Irish market. Following on from this, lack of activity with regards revamping the electrical grid will undermine efforts to reach the aforementioned EU renewable energy targets (EirGrid, 2008a). Finally, the lack of strong

European interconnectors is a critical issue that must be addressed. As mentioned in ∫1.4, Ireland is currently in a state of vulnerability due to its isolated location and the aforementioned lack of interconnectors. From this, it is taken that in order to achieve security of supply, further interconnectors will be required.

4.2.1 Turlough Hill

Turlough Hill is relevant to this project as currently the plant is the solitary pumped storage system in Ireland. The plant's output stands at 292MW (recently, an additional 70MW pumped storage system Knocknagreenan, Co. Cork has been sanctioned) (Department of Communications, Energy & National Resources, 2010a). Components of the Turlough Hill pumped storage system comprise of 4 reversible pump-turbines (ESB, 2005). The same source highlights a number of the systems "constraints" (2005). One such constrain the maximum energy the plant can produce stands at 1.59GWh. Furthermore, system security is cause for added criticism. It is stated that "available energy from the upper reservoir must not drop below 0.3GWh for system security reasons" (ESB, 2005). For example, should the reservoir drop below 0.3GWh, the plant would not be capable to "black start" (ESB, 2005) which is the procedure of restarting a plant without depending on energy from the grid. Additionally, disapproval of the performance of the systems components is evident. The system cannot pump at MW levels outside of the 70-73MW load (ESB, 2005). This system is merely utilised to provide additional energy during peak demands when conventional generation plants are not capable of providing instant power (ESB, 2008). However, the integration of the wind-powered 1815MW approx. pumped storage systems in the West of Ireland has the ability to provide large-scale energy and play a fundamental role in the electrical grid.

4.3 Grid25 & West of Ireland Pumped Storage Systems

The main concern of the Grid25 strategy is the long-term development of the grid to facilitate future requirements (EirGrid, 2008a). Central to this development is the supply of “high-quality, high-voltage bulk power” across the different regions of the country (EirGrid, 2008a). The strategy also entails the harnessing of renewable energy sources to act as a means of mitigating carbon emissions. Additionally, European electrical grid interconnections are intended to facilitate the trade of electricity (EirGrid, 2008a). Essentially, the upgrade of the electrical grid will provide a 60% increase in capacity to accommodate future demands.

The benefits of integrating the combination of pumped storage systems into the electrical grid can be seen from EirGrid’s studies. EirGrid outline that “generation creates a much greater and immediate impact on the grid than demand increases” (2008a), which indicates that a large scale pumped storage system would have the ability to provide for steady demand increases. The requirement for a means of storage and an updated grid is evident in further penetration of renewable energy. Furthermore, EirGrid (2008a) are focusing on conventional generation plants to provide reliable energy whilst wind energy is low, which is a role that can be played by pumped storage systems. Pumped storage has the ability to fill a niche in this instance as a clean and reliable source of energy is attainable from the system (Deane, 2009).

With regard to exporting goals, the currently under construction East–West interconnector between Ireland and Britain will play a central role in the trade of electricity. In addition to the 500MW East-West project, it is planned that a further interconnector, between either Britain or France, will be installed by 2025 (EirGrid, 2008a).

4.3.1 Update of Electrical Grid

Increased electricity demands, further penetration of renewable energy, the location of generation plants and points of interconnection are the primary drivers for an update of the electrical grid (EirGrid, 2008a). 800km km of 220kV lines or higher (likely to be 400kV lines) will be installed while a further 350km of 110kV lines will be established. Furthermore, 2,300km of the existing 220kV line will be upgraded and similarly an upgrade of 1200km of the existing 110kV is intended. (EirGrid, 2008a). Building 400kV lines, as opposed to 220kV lines, provide greater efficiency and capacity (EirGrid, 2008a). As can be seen in Figure 4.2 (which depicts the proposed expenditure by region), the North West- despite being relatively week in terms of grid infrastructure (EirGrid, 2008a) - region will be subject to the third largest investment. (The Grid25 strategy categorises Galway and Mayo as North West).

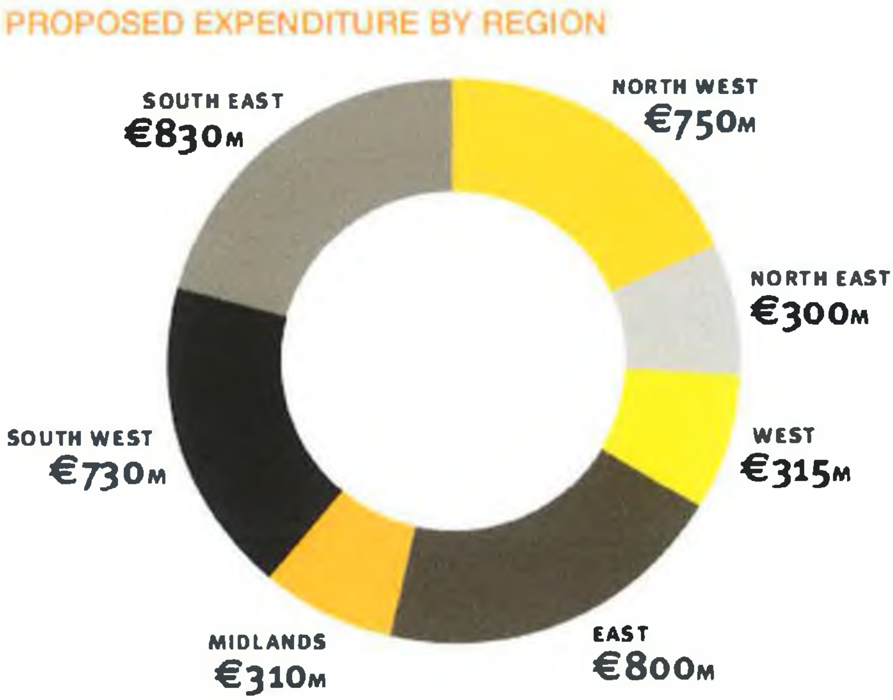


Figure 4.2: Proposed Expenditure by Region (EirGrid, 2008a)

4.3.2 West of Ireland Development

As illustrated in the transmission system map of the island's electrical grid (see appendix) (EirGrid, 2010), the West of Ireland is a weak section of the electrical grid, which consists of 110kV lines with minimal 220kV lines installed. The sole 220kV line in the area is to be extended into Sligo, whilst new 110kV developments are planned in Co. Mayo between Castlebar and Tonroe (EirGrid, 2008a). Post development work, there will be 3 connections to 220kV lines from 110kV lines within Connaught. The West coast of Connaught is forecast to have 880MW of wind generation by 2025 (EirGrid, 2008a). Judging by EirGrid's proposals the power generated in the region is connected to the 110kV line and transmitted around the country via the 3 Connaught based 220kV stations.

4.3.3 Pumped Storage Systems Integration

The Grid25 strategy provides little scope for the integration of a pumped storage system. As outlined in ∫1.4.1, Tokyo's pumped storage systems have utilised up to 1000kV lines to transmit power whilst 400kV lines are planned for the currently under construction Ingula pumped storage system. Whilst studying Ireland's existing grid, the 845MW Moneypoint plant is connected to two 400kV transmission lines. Considering this proposed pumped storage system with an 1815MW output, the optimum means of transmitting the power would be via 400kV lines. This conclusion was reached by considering the 1815MW to be the power fed to the grid, regardless of which transmission line is used. From here, the important element is the force (V) at which flow of electric charge (I) is carried. Therefore, a 400kV line can provide a greater voltage than say 275kV, 225kV or 110kV lines. By this rationale the ultimate transmission lines would be to utilise what is known as ultra high voltage lines (≥800kV), however such plans are far from EirGrid's proposals in the Grid25 strategy. The ideal means of transmitting this electricity is via HVDC (High Voltage Direct Current) rather than Alternating Current (AC) as it facilitates reduced losses and its ability to connect "generating plants remote from power grid" (Drobik, 2009) which is extremely favourable for the purpose of connecting this pumped storage project.

However, the Grid 25 strategy's solitary proposed 400kV line is the North-South interconnector between Belfast and Dublin (EirGrid, 2008a). This leaves the West of Ireland isolated in terms of extra high voltage transmission lines. The author has outlined suitable options for the integration of the pumped storage systems into the electrical grid. These are as follows:

Option 1: the first proposal is the more accommodating of the Grid25 proposals (Figure 4.3). The option centres on connecting an extra high voltage line (>220kV) which facilitates all pumped storage systems to the most northerly of the existing 400kV lines- which will be subject to "significant development" under the plans (EirGrid, 2008a). This will facilitate transmission of power around the country and access to the East-West and North-South interconnectors. The shortest distance from the sites to the 400kV is to place the transmission lines undersea however to integrate the option (as far as possible) into the existing plans of the Grid25 strategy, it was decided to keep all transmission lines onshore.

The formation of this option is illustrated in Figure 4.3. The blue lines represent the high voltage transmission line which is connected to the most northerly of the existing 400kV line. The length of such a line is approximately 275km (902,290ft.). This enables the cost of such a line to be calculated as 1ft. of an over ground transmission line costs approximately €7.80. Therefore, the cost estimate of Option 1 is €7million.

Figure 4.3: Grid Connection Option 1

Option 2: considering the higher efficiency and capacity of 400kV lines, it is proposed to establish a 400kV line from Site 1 to Rush North Beach, Co. Dublin- which is the location of the East-West interconnector (EirGrid, 2008b). Site 2 and Site 3 will be connected to the 400kV line by 220kV lines as depict in Figure 4.4. Integrated within the 400kV line will be substations to facilitate further power transmission to the existing 220kV lines. This option is conflictive of Grid25's plans regarding the solitary 400kV line (North-South Interconnector). However, although not evident in the proposed grid formation, 800km of extra high voltage (>220kV) has been allowed for in the project description. Therefore, considering the distances from the pumped storage systems to the interconnector (as illustrated in Table 3.13), it seems feasible that a portion of this 800km of high voltage transmission lines can be utilised to connect the pumped storage system to the East-West interconnector. Conjointly, this line can be utilised to transfer energy to the highest demand area in Dublin.

Figure 4.4 depicts Option 2. The black circles on the proposed 400kV line represent the substations which will facilitate power to be transmitted on to the 220kV lines and into the Dublin city area. To calculate a cost for the line, the same method was utilised as seen in Option 1. The distance of the line from site 1 to the East West interconnector at Rush North Beach was calculated as 273.5km (897,309ft.). On top of this, an estimated 48km (157,480ft.) of 220kV lines will be required. Taking the cost of 1ft. of an over ground transmission line to be €7.80, the total cost (excluding substations) for the line is calculated as €8.2m.

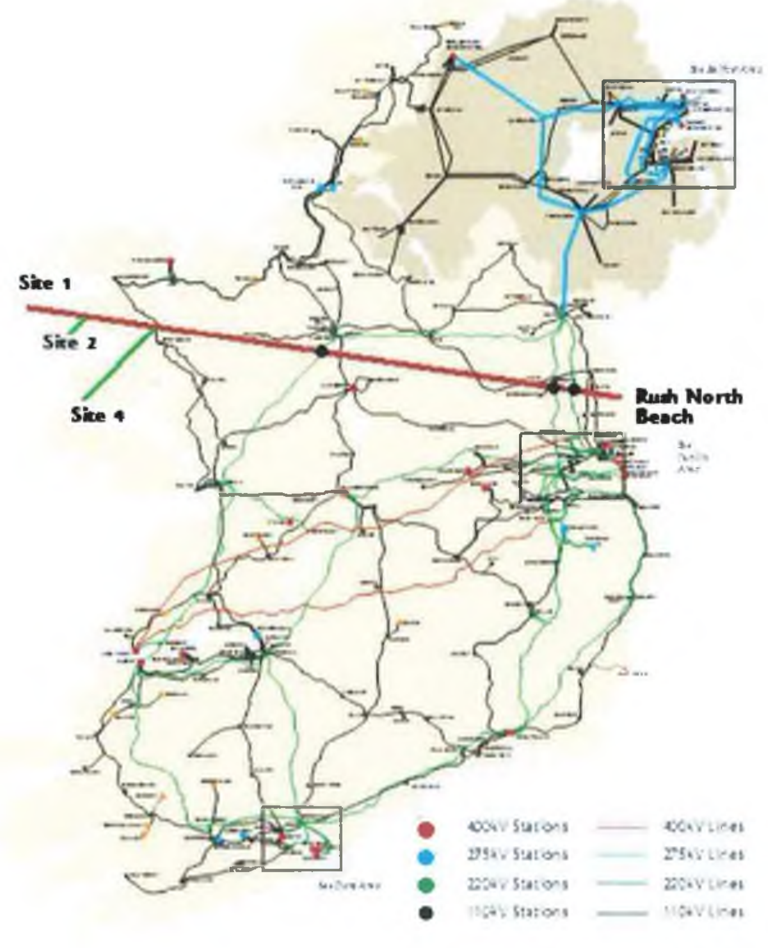


Figure 4.4: Grid Connection Option 2

4.4 Conclusion

It is evident from research that Ireland would benefit from the construction of the wind-powered pumped storage systems. This opinion was formed as such systems would aid further renewable penetration; provide a load balancing effect and market competitiveness. The proposed extensive overhaul of the electrical infrastructure- as detailed in the Grid25 strategy- will provide the country with a more capable grid of meeting demands and exporting goals. However, proposed electrical grid development does not facilitate a large-scale power plant in Ireland's West. It has to be expected that the integration of such a project would require an element of grid restructuring to facilitate the power output. Therefore, the two suggested options of pumped storage grid integration are deemed to be reasonable in the context of the proposed extensive revamp of the electrical grid. Studies have outlined that storage can be beneficial when it comes to 50% renewable penetration (Department of Communications, Energy & National Resources, 2010a). Therefore, due to the setup of the proposed grid, it can be viewed that EirGrid and the Department of Communications, Energy & National Resources have ruled out a West of Ireland pumped storage system in favour of increased interconnection. However, it remains to be seen if interconnection can facilitate load balancing in the same manner as that of pumped storage. Therefore, it is stressed that pumped storage can have an important role to play and should be the subject of further research by authorities.

Chapter 5 – Case Study

5.1 Introduction

This case study is based on the energy situation in South Africa and the role of pumped storage systems within the country's energy strategy. This is particularly relevant to the feasibility of a West of Ireland pumped storage system as South Africa requires a revamp of its existing energy industry and Eskom (the Electricity Supply Commission) have decided to construct two pumped storage systems to cope with increasing demands (Louwinger, 2008). Energy in South Africa, the pumped storage site selection process, the Ingula pumped storage system and ecological conservation measures practiced will all be discussed in this chapter.

5.2 Energy in South Africa

The electricity output of South Africa stands at 40,000MW. This output is to be doubled by 2025 due to an expected increase in peak demands (Louwinger, 2008) and the South African Government's aim to GDP growth to 6% (Ndimande, 2008). The main source of the county's energy supply is peat and coal (72.1%) while oil contributes to 12.6% of this supply (EIA, 2010). Due to the heavy use of these sources, the nation's carbon emissions level is high (EIA, 2010). Hydro currently contributes 0.1% to South Africa's power supply (EIA, 2010). The state of the energy industry in South Africa has highlighted a requirement to diversify the energy supply.

Eskom, the state-owned electricity utility, formulated the Integrated Strategic Electricity Plan (ISEP) to permit "future power and energy demands to be met as economically as possible" (Louwinger, 2008). Strategic measures formulated to cope with the anticipated increase in demands and power output entail a revamp of the existing electrical grid and the construction of new generation plants which will be utilised to provide an extra 3,000MW per year (Ndimande, 2008).

ISEP have outlined the requirement for 2 pumped storage systems. This requirement is due to the anticipated rise in peak demands. Research into the feasibility of pumped storage systems in South Africa date back to the mid 1980's when a site selection process was carried out. This site selection process produced 90 potential sites for the system (Louwinger, 2008). Today, this number has been reduced to 2 which will be utilised for the construction of two pumped storage systems, namely the Ingula and Lima pumped storage systems (Louwinger, 2008).

5.2.1 Pumped Storage Site Selection

Prior to the site selection process, Eskom established key design criteria which were integral to discovering suitable sites. These design criteria included:

- Reservoir capacity
- Distance between reservoirs
- Rated power of turbines

However, for the initial site selection process Eskom removed limitations such as reservoir capacity and feasibility of grid connection in order to identify as many suitable sites as possible. With regards the head of these 90 sites, the range of head recorded was in the 220-610m whilst the generation capacity range was deemed to be in the 400-2,000MW range (Louwinger, 2008). Following on from the selection of the 90 sites, Eskom identified a number of parameters in order to ascertain the most suitable of these 90 sites. These parameters included:

Potential Capacity: the desired generation output was a minimum 1,000MW.

Location from main demand and generation centres: the purpose of this parameter was to reduce transmission loss and transmission line costs. In addition, the site should be surrounding areas of the electrical grid.

Head: The ideal operating head was decided to be in the 400-700m range.

Accessibility: existing infrastructure must provide a means of access to the site. (Louwinger, 2008)

The number of potential sites was reduced to 7 following the feasibility studies. Studies on these 7 sites were carried out between 1987 and 1995. At this point, the number of suitable sites was reduced to 3. Further feasibility studies were carried out on the remaining Ingula, Lima and Mutale sites. These sites were subject to Environmental Impact Assessments, detailed geotechnical investigations, an update of original design and a re-evaluation of each system (Louwinger, 2008). These studies deemed the Mutale site unsuitable for a pumped storage system due to the "slope instability of the upper reservoir basin" and "the occurrence of geological joints at the site" (Louwinger, 2008). Presently, a pumped storage system is under construction at the Ingula site whilst the establishment of a 1500MW pumped storage system at the Lima site is currently at the planning stage.

5.2.2 Ingula Pumped Storage System

Construction works on the Ingula pumped storage system began in 2007 and are scheduled to cease in 2012. The system is situated within the Drakensburg Mountains and entails the construction of the Bedford Dam which will form the upper reservoir and the Bramhoek Dam which encloses the lower reservoir (Eskom, 2008). The reservoirs are 4.6km apart (Eskom, 2010) whilst the capacity of these reservoirs are 26 million metres^3 (Eskom, 2008). Other system components include a powerhouse complex which is connected to the electrical grid to facilitate pumping and transmission of power generated. 4 333MW Francis pump-turbines are included in the powerhouse complex which create a generating capacity of is 1,332MW. The rate head of the system is 441m (Louwinger, 2008). Figure 5.1 illustrates a view of the project which depicts the components of the system such as the upper and lower reservoirs, the powerhouse complex and the penstocks.

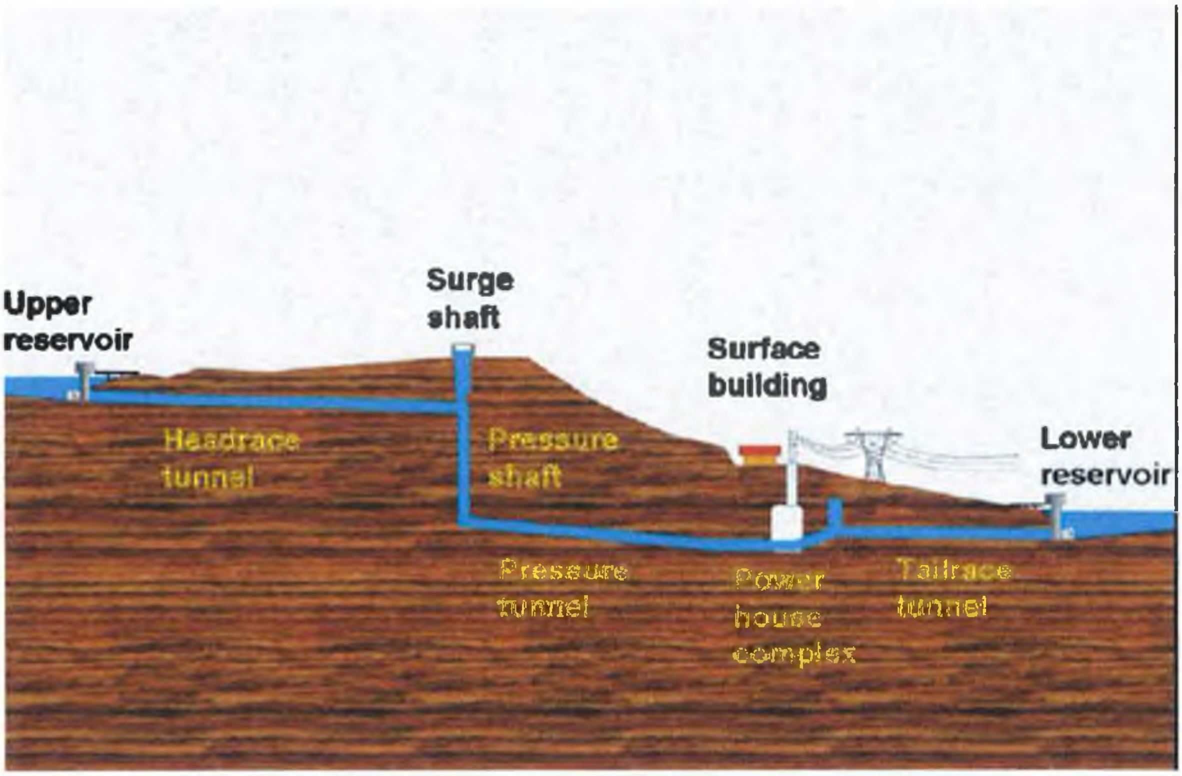


Figure 5.1: Ingula Pumped Storage System (Louwinger, 2008)

An aim of the project is to be recognised as "an internationally renowned sustainable conservation area" (Eskom, 2010). To achieve this, a number of measures are planned. As the upper reservoir is located in an environmentally sensitive area, planners have outlined that the site is to be dealt with as a conservation site. Environmentalists are present on site to overlooks the works and certify that legal requirements are upheld. Additionally, a series of walking and hiking routes will be incorporated in the environs of the pumped storage system as a means of preserving the existing setting of the site (Eskom, 2010).

With regards grid connection of the pumped storage system, it was found that the Ingula pumped storage system transmission line is a 400kV line which is 94km in length. The line runs from the pumped storage system to the Venus substation (NCC Environmental Serives, 2009; eThembeni Cultural Heritage, 2008).

5.3 Discussion

Although circumstances differ, it is clear that the electrical industries of both South Africa and Ireland are experiencing a change. This is represented by the targets which are outlined for each nation. With Ireland aiming to produce 40% of electricity from renewable sources and South Africa targeting a more diversified industry and a 40,000MW increase in supply, it is clear that there is scope to upgrade electricity supply measures in both counties. Similarities are evident in previous means of electricity generation. Peat, coal and gas have been seen as almost ubiquitous sources of energy for both countries (EIA, 2010; Table 1.1) which ensures high levels of carbon emissions were experienced. In addition, the 150% increase in Irelands electricity demands (EirGrid, 2008a) and expected increase in peak demands in South Africa (Louwinger, 2008) brings in the option of pumped storage. South Africa has been the more proactive country in establishing pumped storage systems, while Ireland has shied away from the technology, as discussed in ∫1.5. However, the contrast in approaches towards large scale storage is largely due to the nature of the aforementioned targets. A large scale Pumped storage system, such as the Ingula and Lima plants, can be an extremely effective means of achieving the additional 40,000MW due the large energy output. However, the advantages of utilising pumped storage to regulate wind energy's intermittency are not acted on by EirGrid who prefer to concentrate on increasing interconnection (EirGrid, 2008a).

Considering the fact that South Africa's site selection process began in the 1980's, the indication is that planning the construction of a pumped storage system is a lengthy process. In addition, considerably more sites were identified in this process than the 5 sites which were analysed in this study. Therefore, the consensus is reached that discovering the optimum site for a pumped storage system in Ireland may require extending the boundaries of the location of the plant.

Similar to Ireland's energy situation, restructured dynamics in electricity generation will require changes to South Africa's electrical grid. With regards the Ingula pumped storage system, the construction of the 94km 400kV line to transmit the plants power is not unlike Option 2 outlined in ∫4.3.3. Although the transmission distances differ, the work carried out in South Africa ensures that connection of a pumped storage system to the electrical grid in such manner is feasible. Therefore, due to the higher efficiency and capacity of the 400kV line, this option is viewed as the best option with regards transmission of the pumped storage systems power output.

Work on the Ingula pumped storage system highlights opportunities to enhance the environmental aspect of a West of Ireland pumped storage system which will enable the task of acquiring planning permission easier. The author suggests that the design team of the pumped storage system integrate measures to conserve the area surrounding the site into the management of the plant. This will require the employment of environmentalists to study and analyse the pumped storage operation and to oversee on-site practices. In addition, the establishment of walkways and hiking routes can be viewed favourably as it can accommodate for the damage caused to the existing setting.

5.4 Conclusion

It is clear from the research that pumped storage has a large role to play in the supply of electricity. Although South Africa's motives for the construction of pumped storage systems differ to the renewable energy factor that is being focused on by EirGrid, the integration of the Ingula pumped storage systems can be viewed as an exemplar should a West of Ireland pumped storage system be authorised. One point of interest concerns the duration from initial planning to commencement of construction, which is in excess of 20 years. If a similar approach is taken in the planning of a West of Ireland pumped storage system, the 2020 deadline for renewable energy targets would have passed. At this point, it is anticipated that renewable penetration would be in the 50% region. At this point, pumped storage can be used to mitigate the curtailment of wind and to reduce electricity costs for consumers (Department of Communications, Energy and Natural Resources, 2010). What this means is that for pumped storage to be effective once 50% renewable penetration is reached then immediate commencement of significant research is advised in order to optimise the effects of a pumped storage system.

Chapter 6 – Conclusions & Recommendations

6.1 Conclusions

It is evident from the research that the energy industry in Ireland is on the brink of a change. This is particularly apparent in the establishment of the EU Renewable Energy Targets. Furthermore, the fact that the Irish Government intend on exceeding the aforementioned targets to 40% renewable penetration by 2020 indicates that a swift rate of change is expected. Findings from the research outline that pumped storage has the ability to be an effective integrator of renewable energy into the Irish market. The sporadic nature of wind energy requires a regulator in order to fully capitalise on the resource. Due to its load balancing effect, pumped storage has the ability to convert the intermittent resource into a controllable form of clean energy. Objectors of the previously proposed nuclear plants on Co. Wexford can be appeased by the safe, reliable and practical operation of pumped storage systems. Further to this, the designs of the systems are ever advancing which ensures that construction of pumped storage systems in the West of Ireland has the ability to be viewed as an exemplar. The integration of wind power and seawater provide cutting-edge features to a mature technology which maximises the use of natural resources and creates an unprecedented combination which can highlight Ireland an innovative and proactive in terms of harnessing renewable energy. Such possibilities ensure the popularity of pumped storage is about to rise. The benefits of pumped storage outweigh the associated high construction costs, long construction periods and environmental impacts which can be viewed as negative factors of integrating a pumped storage system. As Ireland's topography is suited to that required for pumped storage systems, it is important that in-depth feasibility studies are carried out as at present, this potential is not recognised. Large scale projects have been constructed around the globe whilst Ireland's enviable topography has remained undeveloped which, when considering the vast area of land is consumes, is a waste in terms of engineering potential.

Ultimately, identification and analysis of the selected sites concluded that there was no one site that was suitable to construct one large scale pumped storage system. However, the

1816MW combined pumped storage systems provide power suitable for Ireland to reach energy independence and ultimately enough power to achieve exporting goals. Entailed within this setup are a number of drawbacks. First of all, it would be prudent of planners to construct one of the systems initially, before works on the other systems in order to study the operation and identify where improvements can be made. Secondly, the combination of the three pumped storage systems will involve increased construction costs, environmental impact and social impact. The most critical aspect of the site selection process was the head of each site. As stated, 400m was the template which was worked off, which would have enabled large scale power output from one site. However, the importance of a clean, constant source of energy was the overriding factor. Therefore, the site selection process was a success as three sites were identified for three relatively large plants (with regards Ireland) which when connected highlights that a large scale pumped storage project in Ireland is feasible.

Inadvertently, the selection of the three most feasible sites resulted in a project similar in setup to the proposals of the Spirit of Ireland initiative. However, this report has succeeded in reducing the number of plants by two and reducing the number of turbines utilised to pump water. It is essential these turbines have connections to both the pumped storage project and the electrical grid to maximise the efficiency of use of the wind, as discussed in §3.5.4. Matching pumping times with high wind speeds and low demands will entail a balancing act, however, the connection to the electrical grid will permit access to conventional power and therefore, energy will constantly be available from the systems, albeit, from a different energy source. Due to wind's intermittency, it is suggested to plan pumping times in accordance with forecast wind speeds on a day to day basis.

Pumped storage has a role to play in the Irish energy market however; constructing the project at this point in time would simply be an unsustainable process due to the state of the existing grid. This proposed 1815MW output is unprecedented in the Irish energy industry and would threaten the security of supply. Therefore, the update of the grid is a critical element. It is also important that planners look further than Turlough Hill when investigating the feasibility of pumped storage systems as there may be a case for planners to be wary of constructing new builds when the existing pumped storage systems is ineffective. The construction of the proposed 70MW Knocknagreenan pumped storage system may also have an effect on EirGrid's and the Governments policy towards pumped storage. The potential success of the plant has the ability to influence planners to upgrade in large scale power outputs such as this proposed project.

Updating the condition of the existing will benefit the energy industry in a number of ways. The targets of the Grid25 strategy cannot be questioned however, the methods of achieving these goals effectively mitigates the role the West of Ireland can play in an updated grid. It is accepted that EirGrid have accommodated increased generated wind power capacity which flow onto the grid when generated. However, it has to be stressed that saving this energy to power the pumped storage system and subsequently utilising this power to cater for peak demands is a more sustainable and efficient process than letting the wind generated power to be utilised as and when needed. There may be a case that the inherent West of Ireland suitability for such a project may be capitalised upon if the infrastructure was already in place; however, it remains a weak point in the grid. Effectively, the west of Ireland does not accommodate large scale electricity generation, be it renewable or conventional. The two grid connection options were formulated to highlight that with the right investment and strategy, the West of Ireland can be utilised as the rechargeable battery not only of Ireland but for Europe via interconnectors.

The construction of a West of Ireland pumped storage system is feasible. The number of systems entailed in the project may have tripled in order to supply large quantities of energy, however this is not deemed to be a critical element. The crucial elements are the aforementioned problems with the electrical grid and the attitude towards pumped storage at Government and TSO level. EirGrid's studies have identified pumped storage as a potential possibility, however the system is not deemed to be worthwhile at 40% renewable penetration. EirGrid recognise the benefits of pumped at 50% renewable penetration however their focus is now on interconnection, 50% renewable penetration is deemed to be a high penetration level of an intermittent source which at times will create an imbalance with regards a renewable/conventional source ratio. The advantage of pumped storage over interconnection is that it provides a constant source of clean energy which is a point which should be central to EirGrids goals. Pumped storage will have a central role to play in the changes of energy industries globally, however it remains to be seen if Ireland will act on its inherent opportunities to set a standard in terms of innovative energy production.

6.2 Future Recommendations

The first recommendation centres on the feasibility of offshore wind harnessing at the West of Ireland. Ireland possesses an inherent opportunity at the Western tip of Europe to capitalise on the higher wind speeds which when harnessed by large scale turbines, an increased output can be achieved. The higher wind speeds and probability rating (Table 3.2) are two elements which can reduce the use of electricity from the electrical grid in the pumped storage project as greater power can be generated on a more consistent basis. Therefore this mitigates the problem of matching pumping times with high wind speeds to a degree however, forecast analysis will still have an integral role to play to manage the resource. Ireland have a solitary wind farm (Arklow Bank) however, when considering the resources, the feeling is that this number should be increased.

Secondly, feasibility studies into the utilisation of freshwater in pumped storage systems are recommended. Site 4 and Site 5 from the site selection process were located in the vicinity of a large lake which could supply a source of water to the pumped storage system. Although ultimately utilising seawater was the most feasible option due to its distance from the site, there may be a case where it is more feasible for future selected sites to integrate the supply into its operation which may reduce friction losses in a system, depending on site specifics.

In order to optimise the results for the feasibility of a West of Ireland pumped storage system, it is recommended that further studies focus on alternative areas along the West of Ireland. This entails similar site selection and grid connection studies to be carried out in the Donegal/Leitrim/Sligo and the Clare/Kerry/Cork regions which have the ability to optimise feasibility results for a pumped storage system in Ireland. The production of such a result can give EirGrid and the Government options to consider with regards policy on storage. These parties can identify with the situation in South Africa and subsequently utilise a similar site selection process used by Eskom. The use of such a site selection process will maximise the number of potential sites, which is what will be required before commitment to such a large project.

Finally, as the 70MW Knocknagreenan pumped storage system is still in early planning stages, it is suggested to integrate the renewable wind energy into the system specifications. This will enable a first-hand view of the performance of the system on a relatively small pumped storage system. From this, the performance of the system can be extrapolated to identify the impact a large scale 1815MW pumped storage system.

References

Allen, P., & Randell, A., (2006). *Climate change and peak oil pose a formidable challenge to our security, values and way of life.* Available from: http://www.ecodyfi.org.uk/energy/powerdown.htm [accessed 6th June 2010].

American Society of Civil Engineers, (1996). *Task Committee on Pumped Storage.* Available from: http://books.google.ie/books?id=iCSl-pxL7IwC&source=gbs_navlinks_s [14th June 2010].

Asian Development Bank, (2001). *Project Completion Report.* Available from: http://www.adb.org/Documents/PCRs/PRC/26369-PRC-PCR.pdf [accessed 16th July 2010].

Azevado, K., Demars, R., Gomez, T. & Parichit, K. (2008). Available from: http://www.srl.gatech.edu/education/ME6105/Projects/Fa08/KA-RD-TG-PK/ME6105.HW2.Azevedo.DeMars.Gomez.Kumar.pdf [accessed 16th June 2010].

Bryan, L., (2009). *Cost of pumped hydro storage.* Available from: http://www.wind-watch.org/documents/cost-of-pumped-hydro-storage/ [accessed 17th July 2010].

Bureau of Labour Statistics, (2009). *Occupational Outlook Handbook, 2010-11.* Available from: http://www.bls.gov/oco/ocos005.htm [accessed 17th July 2010].

Carbon Pros, (2009). *Energy Smart: Pumped Hydro.* Available from: http://carbon-pros.com/blog1/2009/09/energy_smart_pumped_hydro.html [accessed 14th June 2010].

Chaplygina,E., (2010).*Outlook for Utilisation of Variable Speed Turbines.* Available from: http://www.springerlink.com/content/r2x0701818552763/ [accessed 28th August 2010].

Collier County, (2009). *Vegetation Removal, Protection and Preservation.* Available from: http://library.municode.com/html/13992/level2/CHAP3_3.05.00.html [accessed 10th July 2010].

Corcoran, A, Breslin, E, & McCormack, L., (2009). *Dramatic Wind Power Solution to Irish Economic Crisis.* Available from:

http://www.spiritofireland.org/content/documents/pressrelease.doc [accessed 13th June 2010].

Deane, J., Gallacher, B., & McKeogh, E., (2009). *Techno-economic review of existing and new pumped hydro energy storage plant.* Elsevier. [Online] **14** (November). Available form: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6VMY-4XV43BM-1&_user=10&_coverDate=05%2F31%2F2010&_rdoc=1&_fmt=high&_orig=search&_origin=search&_sort=d&_docanchor=&view=c&_searchStrId=1462635410&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=6dda56bac0f205ec0fda1474e90a5c8e&searchtype=a [accessed 11th June 2010].

Deane, P., (2009). *Pumped Storage as an Integrator for Wind Energy in Ireland.* Available from: www.ucc.ie/en/eri/ericonferences/document-1-74748-en.ppt [accessed 21st April 2010].

Dell, R., & Rand., D., (2001). *Energy Storage- A Key Technology for Global Energy Sustainability.* Available from: http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6TH1-44CVXGT-2&_user=10&_coverDate=11%2F30%2F2001&_rdoc=1&_fmt=high&_orig=search&_origin=search&_sort=d&_docanchor=&view=c&_searchStrId=1462650762&_rerunOrigin=google&_acct=C000050221&_version=1&_urlVersion=0&_userid=10&md5=5d5f9a78db5a223edaf3bdc4d96bfe84&searchtype=a [accessed 2nd June 2010].

Dennehey, E., Howley, M., Gallacher, B., & Barriscale, A., (2010). *Renewable Energy in Ireland.* Available from: http://www.seai.ie/Publications/Statistics_Publications/SEI_Renewable_Energy_2010_Update/RE_in_Ire_2010update.pdf [accessed 21st August 2010].

Department of Communications, Energy & National Resources, (2010a). *National Renewable Energy Action Plan.* Available from: http://www.dcenr.gov.ie/NR/rdonlyres/C71495BB-DB3C-4FE9-A725-0C094FE19BCA/0/2010NREAP.pdf [accessed 11th August 2010].

Department of Communications, Energy & National Resources, (2010b). *Corrib Gas Field Development.* Available from:

http://www.dcenr.gov.ie/Natural/Petroleum+Affairs+Division/Corrib+Gas+Field+Development/ [accessed 23rd August 2010].

Department of Enterprise, Trade and Employment, (2005). *Irish Electricity Market Principal Challenges.* Available from: http://www.deti.ie/publications/trade/2005/electricitymarket.pdf [accessed 13th June 2010].

Drobik, T., (2009). *High voltage direct current transmission lines.* Available from: http://eeeic.eu/proc/papers/69.pdf [accessed 13th September 2010].

EIA, (2000). *Carbon Dioxide Emissions from the Generation of Electric Power in the United States.* Available from: http://www.eia.doe.gov/electricity/page/co2_report/co2report.html [accessed 21st June 2010].

EIA, (2010). *South Africa.* Available from: http://www.eia.doe.gov/cabs/South_Africa/Background.html [accessed 4th September 2010].

EirGrid, (2010). Transmission System. Available from: http://www.eirgrid.com/media/All-Island%20Transmission%20Map%20(January%202010).pdf [accessed 28th June 2010].

EirGrid, (2009). *Generation Adequacy Report 2010-2016.* Available from: http://www.eirgrid.com/media/Generation%20Adequacy%20Report%202010-2016.pdf [accessed 25th July 2010].

EirGrid, (2008a). *Grid25.* Available from: http://www.eirgrid.com/media/Grid%2025.pdf [accessed 28th June 2010].

EirGrid, (2008b). East West Interconnector. Available from: http://www.eirgridprojects.com/projects/east-westinterconnector/ [accessed 19th August 2010].

EirGrid, (2006a). EirGrid at a Glance. Available from: http://www.eirgrid.com/media/EirGrid%20at%20a%20Glance.pdf [accessed 15th July 2010].

EirGrid, (2006b). *National Control Centre.* Available from: http://www.eirgrid.com/operations/nationalcontrolcentre/ [accessed 11th June 2010].

EirGrid, (2006c). Ireland's Power System. Available from: http://www.eirgrid.com/operations/irelandspowersystem/ [accessed 11th June 2010].

EirGrid, (2006d). *Transmission.* Available from: http://www.eirgrid.com/transmission/ [accessed 11th June 2010].

Electricity Storage Association, (2009). *Pumped Hydro.* Available from: http://www.electricitystorage.org/site/technologies/pumped_hydro/ [accessed 29th May 2010].

Elsafty, A, & Saeid, L., (2009). *Sea Water Air Conditioning [SWAC]: A Cost Effective Alternative.* Available from: http://www.cscjournals.org/csc/manuscript/Journals/IJE/volume3/Issue3/IJE-54.pdf [accessed 8th September 2010].

Enercon, (2007). *World's most powerful wind turbine installed near Emden.* Available from: http://www.enercon.de/www/en/windblatt.nsf/vwAnzeige/66BD14BABA22BCA2C12573A7003FA82E/$FILE/WB-0407-en.pdf [accessed 16th June 2010].

Energy Bible, (2008). *Wind speed and Wind Energy.* Available from: http://energybible.com/wind_energy/wind_speed.html [accessed 17th July 2010].

Energy Resources, (2010). *Energy Resources: Nuclear Power.* Available from: http://www.darvill.clara.net/altenerg/nuclear.htm [accessed 11th August 2010].

Engineering Toolbox, (2008). *Pumps in parallel or Serial Connection.* Available from: http://www.engineeringtoolbox.com/pumps-parallel-serial-d_636.html [accessed 12th June 2010].

Environmental Protection Agency, (2010). *Land Use Land Cover.* Available from: http://www.epa.ie/whatwedo/assessment/land/ [accessed 23rd July 2010].

Environmental Protection Agency, (2006). *Forestry and the Environment.* Available from: http://www.epa.ie/downloads/pubs/other/viewpoints/epa_viewpoint_forestry_sept%2006.pdf [accessed 23rd July 2010].

EPDC, (n.d.). *Okinawa Seawater Pumped Storage.* Available from: http://www.jpower.co.jp/english/international/consultation/detail/se_as_japan24.pdf [accessed 28th May 2010].

ESB, (2005). *All-Island Market Modelling Programme.* Available from: http://www.allislandproject.org/GetAttachment.aspx?id=39f4c30c-0a59-4142-b878-e49d30b0d324 [accessed 24th August 2010].

ESB, (2008). Turlough Hill. Available from: http://www.esb.ie/main/about-esb/turlough-hill.jsp [accessed 11th September 2010].

Eskom, (2008). Ingula Pumped Storage System. Available from: www.eskom.co.za/content/Iss8_P2.pdf [accessed 5th September 2010].

Eskom, (2010). *Ingula Pumped Storage Scheme.* Available from: http://www.eskom.co.za/live/content.php?Item_ID=2329 [accessed 7th September 2010].

Ethembeni Cultural Heritage, (2008). *Heritage Impact Assessment of Ingula/Venus Power Line.* Available from: http://www.eskom.co.za/content/Igula%20Venus%20report%20-%20heritage.pdf [accessed 2nd September 2010].

EurActiv (2007). *EU Renewable Energy Policy.* Available from: http://www.euractiv.com/en/energy/eu-renewable-energy-policy/article-117536 [accessed 21st July 2010].

EurActiv, (2010a). *Irish grid capable of accommodating 40% renewables.* Available from: http://www.euractiv.com/en/energy/irish-grid-capable-accommodating-40-renewables-news-495259 [accessed 17 August 2010].

EurActiv, (2010b). *Integrating Renewables into the Electricity Grid.* Available from: http://www.euractiv.com/en/energy/integrating-renewables-electricity-grid-linksdossier-494846 [accessed 22nd August 2010].

European Environment Agency (2006). *Primary energy consumption by fuel.* Available from: http://www.eea.europa.eu/data-and-maps/indicators/primary-energy-consumption-by-fuel/primary-energy-consumption-by-fuel-1 [accessed 12th August 2010].

Forfas, (2009a). *Statement on Energy.* Available from: http://www.forfas.ie/media/ncc091006_statement_energy.pdf [accessed 22nd July 2010].

Forfas, (2009b). *Reducing Energy Costs is Essential for Competitiveness.* Available from: http://www.forfas.ie/newsevents/news/title,4732,en.php [accessed 13 July 2010].

Finfacts, (2008). *Ireland has the highest electricity prices in Europe for businesses and domestic consumers.* Available from: http://www.finfacts.ie/irishfinancenews/article_1015242.shtml [accessed 12th July 2010].

Fujihara, T., Haruo, I., & Oshima, K., (1998). *Development of Pump Turbine for Seawater Pumped-Storage Power Plant.* Available from: http://www.hitachi.com/rev/1998/revoct98/r4_108.pdf [accessed 8th August 2010].

Galway County Council, (2009). County Development Plan 2009-2015. Available from: http://www.galway.ie/en/Services/Planning/DevelopmentPlans/GalwayCountyDevelopmentPlan2009-2015/CountyDevelopmentPlan2009-2015/FilesTable/Galway_County_Council_DevPlan2009.pdf [accessed 24th July 2010].

Hammill, L., (2001). *Understanding Hydraulics Second Edition.* New York: Palgrave.

Hoeller, P., & Wallin, M., (1991). *Energy Prices, Taxes and Carbon Dioxide Emissions.* [accessed 7th June 2010].

Independent Media Centre Ireland, (2010). *Submission against Shell EIS and CAOs.* Available from: http://www.indymedia.ie/article/97277?userlanguage=ga&save_prefs=true [accessed 27th August 2010].

IEAA, (2009). *Environmental goods and services: could green be the new black for Ireland and the world?* Available from: http://www.iiea.com/blogosphere/environmental-goods-and-services [accessed 12th June 2010].

Irish Wind Turbine, (2010). *Why chose the wind?* Available from: http://www.irelandwindturbine.com/1052.html [accessed 6th July 2010].

Irish Wind Energy Association, (2010). *County Wind Map.* Available from: http://www.iwea.com/index.cfm/page/_windenergy_onshore [accessed 12th August 2010].

Kadar, P., (2009). *Pumped Storage Hydro Plant model for educational purposes.* Available from: http://www.icrepq.com/ICREPQ'09/531-kadar.pdf [accessed 14th June 2010].

Larson, E., (2009). Pumped Storage: *An Unheralded Multiplier for Renewable Energy.* Available from: http://www.hdrinc.com/sites/all/files/content/articles/article-files/2618-pumped-storage-an-unheralded-multiplier-for-renewable-power.pdf [accessed 26th May 2010].

Leyland, B., (2009). *Cost of pumped hydro storage.* Available from: http://www.wind-watch.org/documents/cost-of-pumped-hydro-storage/ [accessed 9th September 2010].

Louwinger, F., (2008). *Case study of Ingula and Lima pumped storage schemes.* Available from: http://www.eepublishers.co.za/images/upload/Gen%20-%20Case%20study.pdf [accessed 17th August 2010].

Mainstream Renewable Energy (2010). Supergrid. Available from: http://www.mainstreamrp.com/pages/Supergrid.html [accessed 18th June 2010].

Martifer Renewables, (2009). *Green Islands Project.* Available from: http://stk4.outbox.ativism.pt/up/ficheiros-bin2_ficheiro_pt_0865247001242751118-51.pdf [accessed 16th August 2010].

MacSimion, A., (2002). *Carnsore: Why Ireland never got nuclear power.* Available from: http://flag.blackened.net/revolt/wsm/talks/carnsore2002.html [accessed 25th June 2010].

Mayo County Council, (2008a). *Landscape Appraisal of Co. Mayo.* Available from: http://www.mayococo.ie/en/Planning/DevelopmentPlansandLocalAreaPlans/MayoCountyDevelopmentPlan2008-2014/PDFFile,7799,en.pdf [accessed 24th July 2010].

Mayo County Council, (2008b). Mayo County Development Plan 2008-2014. Available from: http://www.mayococo.ie/en/Planning/DevelopmentPlansandLocalAreaPlans/MayoCountyDevelopmentPlan2008-2014/PDFFile,7795,en.pdf [accessed 12th July 2010].

McDonald, D., (2009). *How Wind and Hydro Energy Storage will save Ireland €Billions in fuel Imports and Tens of Millions of Tons of Pollutant Emissions.* Available from: http://www.spiritofireland.org/content/repository/how_hydro_energy_storage.doc [accessed 14th June 2010].

McDonald, F., (2010). *Flooded valleys key to huge power plan.* Avaialble from: http://www.irishtimes.com/newspaper/ireland/2010/0301/1224265371780.html [accessed 2nd June 2010].

McKeogh, E., (2007). *Meeting the Challenges of RE Generation.* Available from: http://www.eirgrid.com/media/3)%20Wind%20&%20Pumped%20Storage%20-%20Eamon%20McKeogh%20-%20UCC.pdf [accessed 6th June 2010].

Melia, P., (2010). Race is on to build 250 wind farms for EU 2020 target. Available from: http://www.independent.ie/business/irish/race-is-on-to-build-250-windfarms-for-eus-2020-target-2211157.html [accessed 14th June 2010].

Michigan Department of Technology, Department & Budget, (2010). *Office of Shared Solutions.* Available from: http://www.michigan.gov/cgi/0,1607,7-158-14767-31893--F,00.html [accessed 24th July 2010].

Miller, J., (2010). *The (green) Spirit of Ireland.* Available from: http://newscenter.lbl.gov/feature-stories/2010/07/07/green-spirit-of-ireland/ [accessed 2nd August 2010].

Miller, R. & Winters, M., (2009*). ENERGY STORAGE: Opportunities for Pumped Storage: Supporting Renewable Energy Goals.* Available from: http://www.hydroworld.com/index/display/article-display/366365/articles/hydro-review/volume-28/issue-5/Featured_Articles/energy-storage-opportunities-for-pumped-storage-supporting-renewable-energy-goals.html [accessed 28th May 2010].

Moore, R., (2004). *Tanks.* Available from: http://water.me.vccs.edu/courses/CIV240/lesson13.htm [accessed 27th August 2010].

NCC Environmental Services, (2009). *Environmental Management for Eskom.* Available from: http://www.natureconservation.co.za/index.html?id=38 [accessed 11th September 2010].

Ndimande, B., (2008). *South Africa: Nuclear Power Generation.* Available from: http://www.nema.org/gov/trade/briefs/sa_nuke.pdf [accessed 4th September 2010].

National Offshore Wind Association of Ireland, (2009). *Offshore Wind Energy in Ireland.* Available from:

http://www.nowireland.ie/pdf/Now_Ireland_Policy_Briefing_Document.pdf [accessed 23rd June 2010].

National Parks and Wildlife Service, (2008a). *The Planning and Development Act, 2000.* Available from: http://www.npws.ie/en/WildlifePlanningtheLaw/Legislation/ThePlanningandDevelopmentAct2000/ [accessed 28th June 2010].

National Parks and Wildlife Service, (2008b). *Planning role of NPWS.* Available from: http://www.npws.ie/en/WildlifePlanningtheLaw/PlanningRoleofNPWS/ [accessed 28th June 2010].

O'Connell, S., (2009). *To halt climate change, stop saying no to nuclear.* Available from: http://www.spiritofireland.org/content/repository/to_halt_climate_change,_stop_saying_no_to_nuclear.pdf [accessed 30th May 2010].

O'Connor, (2010). *Renewable energy: A lot of hot air?*. Available from: http://www.businessandfinance.ie/bf/2010/5/interviewfeaturemay2010/renewableenergyalotofhotair [accessed 21st May 2010].

O'Donnell, G., (2009a). *Spirit of Ireland Summary.* Available from: http://www.spiritofireland.org/content/repository/spirit_of_ireland_summary.doc [accessed 12 June 2010].

O'Donnell, G., (2009b). *Ireland has a bright future.* Available from: http://www.spiritofireland.org/content/repository/soi_summary_4_page.doc [accessed 29th May 2010].

O'Donnell, G., (2009c). How Hydro Energy Storage Works. Available from: http://www.spiritofireland.org/content/repository/how_hydro_energy_storage_works.doc [accessed 14th May 2010].

O'Donnell, P., (2009). *How Electricity is Matched to Customer Demand.* Available from: http://www.spiritofireland.org/content/repository/how_electricity_production_is_matched.doc [accessed 4th June 2010].

O'Halloran, (2010). *Transfer of ESB's grid may cost up to €150m.* Available from: http://www.irishtimes.com/newspaper/finance/2010/0705/1224274034764.html?via=rel [accessed 3rd August 2010].

Ordnance Survey Ireland, (n.d.) *Discovery Series Map 30.* Dublin.

Ordnance Survey Ireland, (n.d.) *Discovery Series Map 31.* Dublin.

Ordnance Survey Ireland, (n.d.) *Discovery Series Map 37.* Dublin.

Ordnance Survey Ireland, (n.d.) *Map Viewer.* Available from: http://maps.osi.ie/publicviewer/ [accessed 12th June 2010].

Pacific Pump and Power, (2008). *Friction Loss in Pipe.* Available from: http://www.pacificpumpandpower.com/docs/Friction_Loss_Table.pdf [accessed 4th July 2010].

Renewable Energy World, (2010). *Pumped Hydro and New Energy.* Available from: http://www.renewableenergyworld.com/rea/blog/post/2010/06/pumped-hydro-and-new-energy [accessed 7th August 2010].

RePower, (2010). *Lago Bianco Pumped Storage Power Plant: Concession Project Complete.* Available from: http://www.repower.com/en/group/media/news-releases/en-detailmedienmitteilung/article/lago-bianco-pumped-storage-power-plant-concession-project-complete/?tx_ttnews%5BbackPid%5D=107&cHash=0945a4ba5d1fb3a2f4d34da041fefaa9 [accessed 17th June 2010].

Ruttledge, L., (2010). Electricity Grid. Available from: http://www.dcenr.gov.ie/NR/rdonlyres/5834F65A-F872-46DB-99D1-C60B58F1444B/0/ElectricityGrid.pdf [accessed 16th June 2010].

Shevts, I., (2010). The Frontline. 'The Cost of Fuel and the Carbon Tax'. RTE One. 26th April 2010. 10.30hrs.

Spirit of Ireland, (2009a). *Working together for Ireland.* Available from: http://www.spiritofireland.org/questions.php [accessed 21st April 2010].

Spirit of Ireland, (2009b). *The Solution.* Available from: http://www.spiritofireland.org/solution.php [accessed 16th May 2010].

Spirit of Ireland, (2009c). *Working together for Ireland.* Available from: http://www.spiritofireland.org/ [accessed 24th May 2010].

Stratkraft, (n.d.). *Pumped Storage.* Available from: http://www.risoe.dtu.dk/en/Conferences/Workshop_Sustainable_Energies/~/media/Risoe_dk/Conferences/Energyconf/Documents/Storage/lars_fodstad_tilladelse.ashx [Accessed 17th June 2010].

Symbiotics, (2008). The *History of Pumped Storage.* Available from: http://www.symbioticsenergy.com/projects/pumped/pumped-history.html [accessed 15th June 2010].

Teagasc, (2010). Agriculture in Ireland. Available from: http://www.teagasc.ie/agrifood/ [accessed 25th August 2010].

The Frontline. 'The Cost of Fuel and the Carbon Tax'. RTE One. 26th April 2010. 10.30hrs.

Twenty First Strategies, (2009). *Pumped Storage Hydroelectricity.* Available from: http://www.uspowerpartners.org/Topics/SECTION2Topic-PumpedStorage.htm [accessed 12th June 2010].

Wind Atlas, (2006). *European Wind Resources.* Available from: http://www.windatlas.dk/Europe/EuropeanWindResource.html [accessed 12 June 2010].

World Nuclear Association, (2010). *Nuclear Power in France.* Available from: http://www.world-nuclear.org/info/inf40.html [accessed 13th August 2010].

Wind Atlas, (2006). *European Wind Resources.* Available from: http://www.windatlas.dk/Europe/EuropeanWindResource.html [accessed 29th July 2010].

Wind Energy (2009). *Curtailments.* Available from: http://www.wind-energy-the-facts.org/en/part-i-technology/chapter-2-wind-resource-estimation/local-wind-resource-assessment-and-energy-analysis/the-prediction-of-the-energy-production-of-a-wind-farm/curtailments.html [accessed 11th September 2010].

Wind Finder, (2010a). *Windfinder - Wind & weather statistic Wicklow.* Available from: http://www.windfinder.com/windstats/windstatistic_wicklow.htm [accessed 17th July 2010].

Wind Finder, (2010b). *Windfinder - Wind & weather statistic Connaught.* Available from: http://www.windfinder.com/windstats/windstatistic_connaught.htm [accessed 17th July 2010].

Wind Finder, (2010c). *Windfinder - Wind & weather statistic West of Aran Isles.* Available from: http://www.windfinder.com/windstats/windstatistic_west_of_aran_isles.htm [accessed 17th July 2010].

Wind Finder, (2010d). Available from: http://www.windfinder.com/report/connaught [accessed 21st August 2010].

Yocom, D,. & Helms, M., (2001). *Discharge in the Electric Industry.* European Business Review. **13** (Number 3). Pp. 137-151.

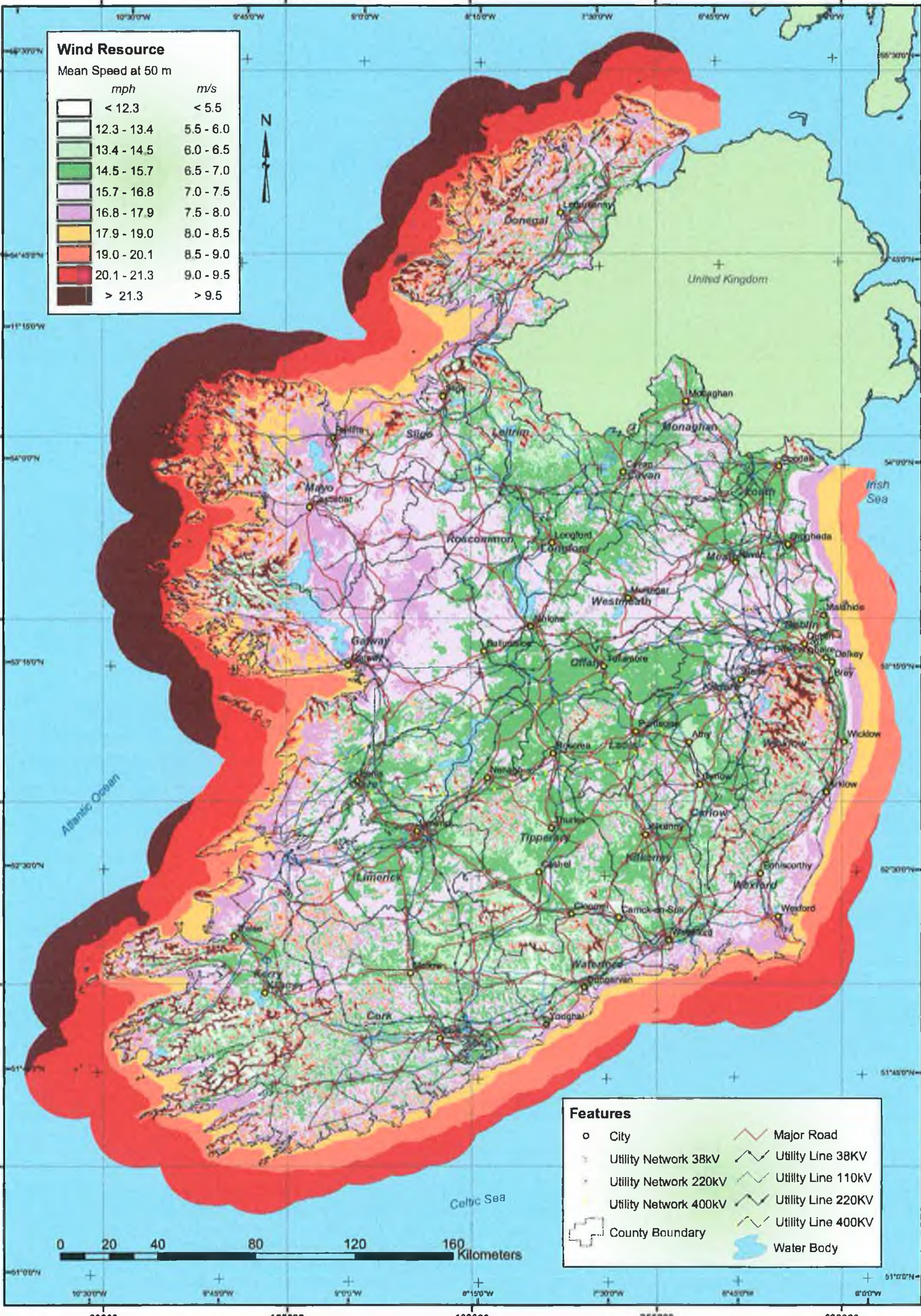
Bibliography

Chadwick, A., (2009). Hydraulics in civil and environmental engineering. London. Spon.

Hughes, E., (2008). Electrical and Electronic Engineeering. New York. Preason/Prentice.

Morley, A. (1994). Principles of Electricity. Harlow. Longman Scientific & Technical.

Wind Speed Map of Ireland at 50 Meters



Coordinate System: Irish National Grid
Spatial Resolution of Wind Resource Data: 200m
This map was created by TrueWind Solutions using the MesoMap system and historical weather data. Although it is believed to represent an accurate overall picture of the wind energy resource, estimates at any location should be confirmed by measurement.

RENEWABLE ENERGY FOR EUROPE

TrueWind Solutions

ESB INTERNATIONAL

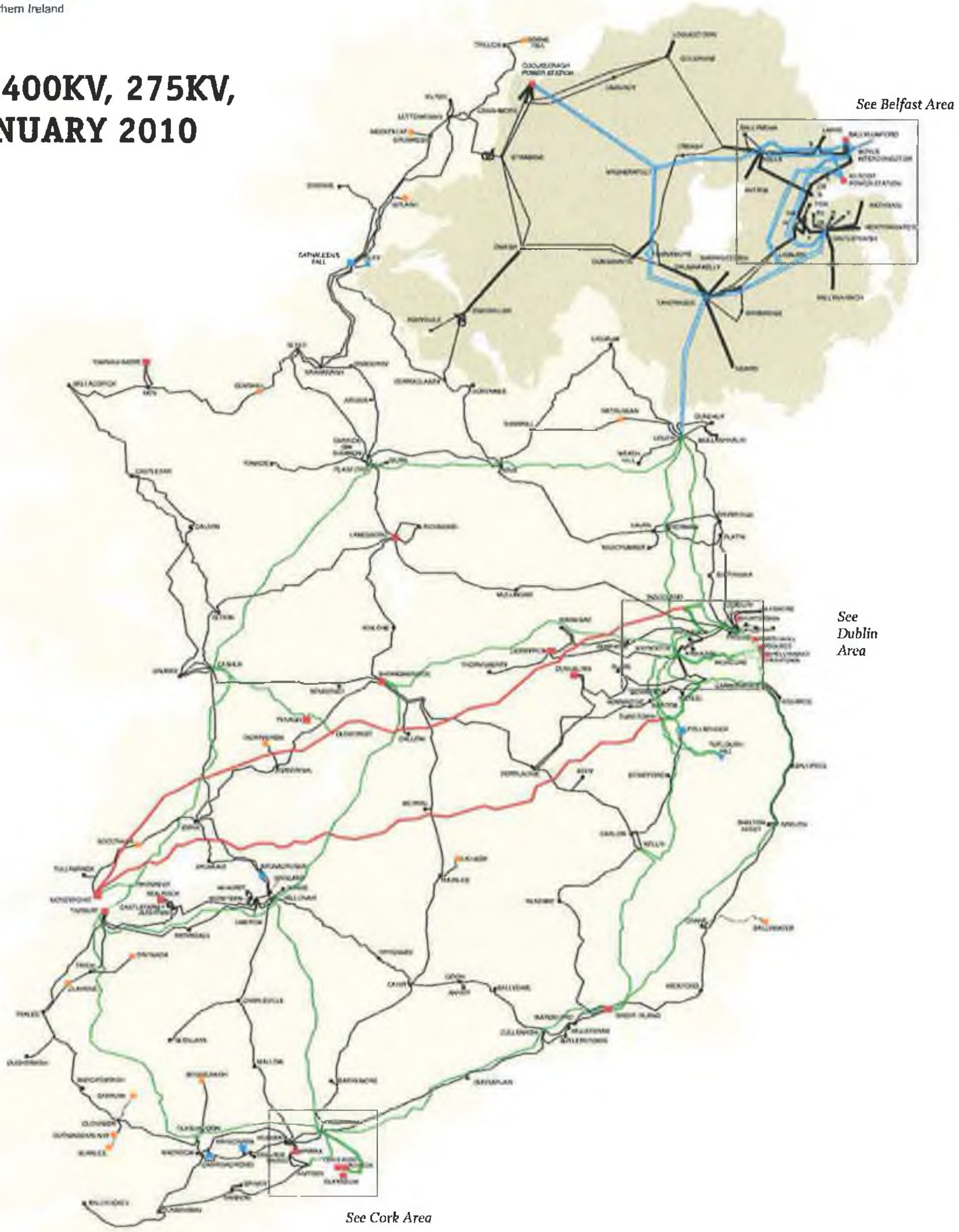
EIRGRID SONI System Operator for Northern Ireland

TRANSMISSION SYSTEM 400KV, 275KV, 220KV AND 110KV - JANUARY 2010

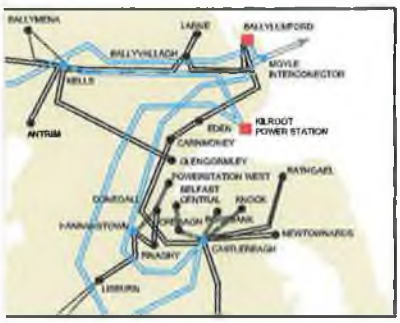
- 400kV Lines
- 275kV Lines
- 220kV Lines
- 110kV Lines
- 220kV Cables
- 110kV Cables
- 400kV Stations
- 275kV Stations
- 220kV Stations
- 110kV Stations
- Phase Shifting Transformer

Transmission Connected Generation

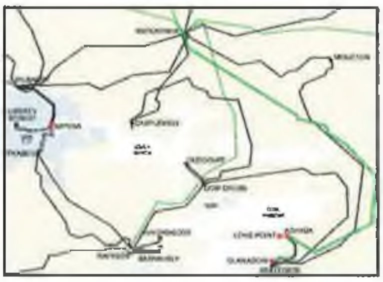
- Hydro Generation
- Thermal Generation
- Pumped Storage Generation
- Wind Generation



Belfast Area



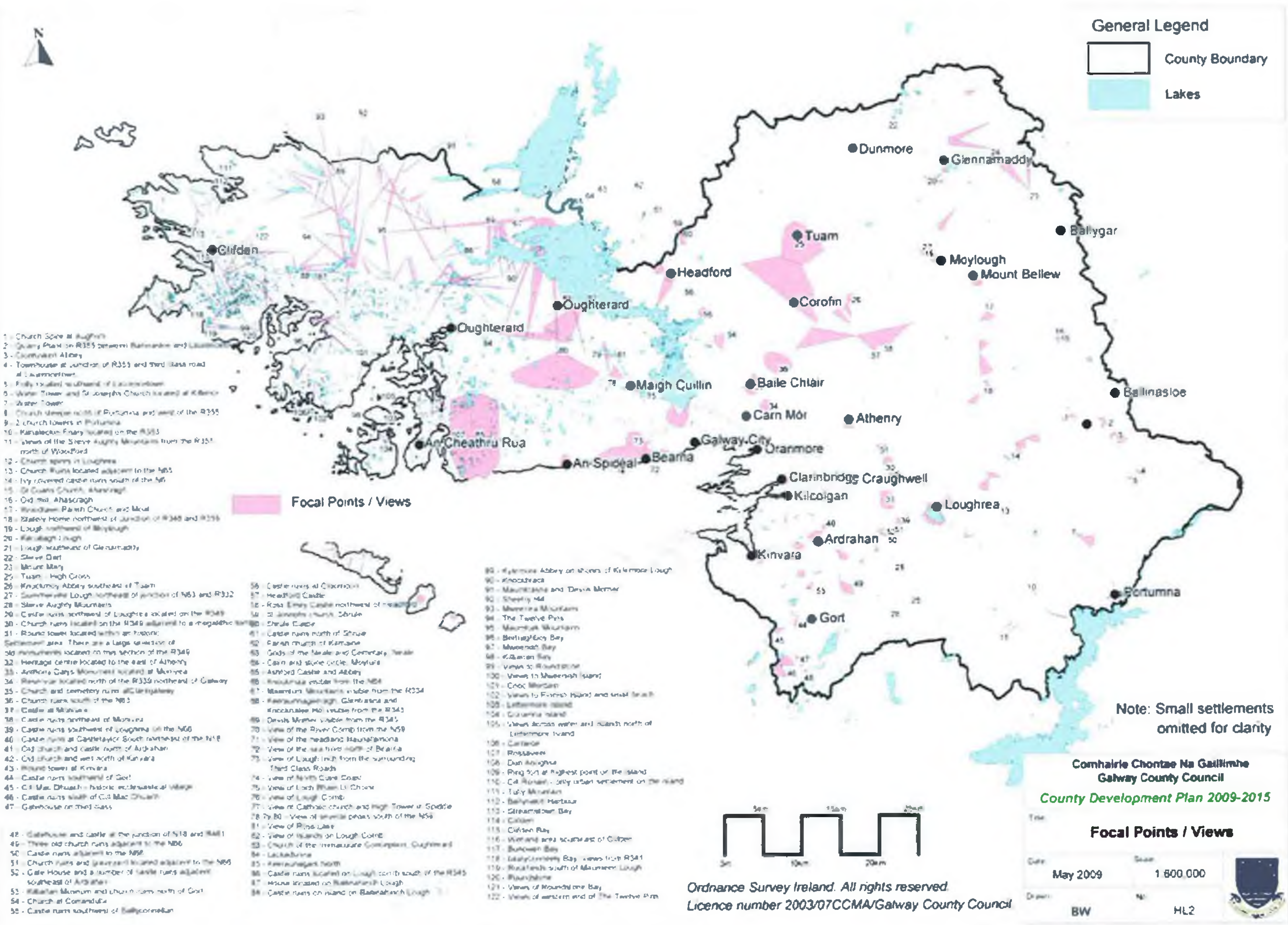
Cork Area



Dublin Area


National Primary Road
National Secondary Road
Regional Road
HIGHLY SCENIC VIEW
SCENIC VIEWING POINT
SCENIC VIEW
SCENIC ROUTE
MAP 10
SCENIC VIEWS

Map HL2



General Legend
County Boundary
Lakes
Focal Points / Views
Dunmore
Glennamaddy
Ballygar
Tuam
Moylough
Mount Bellew
Headford
Clifden
Oughterard
Corofin
Maigh Cuillin
Baile Chláir
Carn Mór
Athenry
Ballinasloe
An Cheathrú Rua
An Spidéal
Bearna
Galway City
Oranmore
Clarinbridge
Craughwell
Kilcolgan
Loughrea
Ardrahan
Kinvara
Portumna
Gort
Note: Small settlements omitted for clarity
Ordnance Survey Ireland. All rights reserved.
Licence number 2003/07CCMA/Galway County Council
Comhairle Chontae Na Gaillimhe
Galway County Council
County Development Plan 2009-2015
Focal Points / Views
May 2009
1:600,000
BW
HL2