ALL ISLAND GRID STUDY

WORKSTREAM 1

RENEWABLE ENERGY RESOURCE ASSESSMENT

January 2008

Department of Communications, Energy and Natural Resources
Roinn Cumarsáide, Fuinnimh agus Acmhainní Nádúrtha

Department of Enterprise, Trade and Investment
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A Report to

The Department of Communications, Energy and Natural Resources

And

The Department of Enterprise, Trade and Investment

By

ESB International

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Abbreviations

AD	Anaerobic Digestion
AFBI	Agrifood & Biosciences Institute (DARD)
ARC21	A group of 11 waste management authorities in the greater Belfast area
AVHRR	Advanced Very High Resolution Radiometer
BMW	Biodegradable Municipal Waste
BNE	Best New Entrant
BnM	Bord na Mona
CAD	Central Anaerobic Digestion
CAP	Common Agricultural Policy
CCGT	Combined Cycle Gas Turbine
CER	Commission for Energy Regulation
CF	Capacity factor
C&I	Commercial & Industrial Waste
CO_2	Carbon Dioxide
CSO	Central Statistics Office (RoI)
DARD	Dept. of Agriculture & Rural Development (NI)
dB(A)	Decibels (Scale A) (Sound level)
DCMNR	Dept. of Communications, Marine and Natural Resources (RoI)
DEHLG	Dept. of Environment, Heritage and Local Government (RoI)
DETI	Dept. of Enterprise, Trade & Industry (NI)
DAF	Dept. of Agriculture & Food (RoI)
E	Standard Error
EC	European Community
EFW	Energy from Waste
EN	Euro Norm (Standard)
EPA	Environmental Protection Agency
ESB	Electricity Supply Board (Ireland)
EU	European Union
FT	Fischer-Tropsch (Biofuel Production Process)
G	Gas Collection Factor
GHG	Greenhouse Gas
GJ	Giga Joule
GWhe	GigaWatthour (electrical)
GWht	GigaWatthour (thermal)
Ha	Hectare
HNV	High Nature Value (Organic) farming
Hs	Significant Wave Height (m)
IFA	Irish Farmers Association
IFS	Irish Forest Service
IMI	Irish Marine Institute
K	Thousand
Ktoe	Thousand tonnes of oil equivalent
kV	Kilovolt
kWe	Kilowatt (electrical)
kWhe	Kilowatthour (electrical)
kW/m	Hydrodynamic Power flux/metre of wave front
LFG	Landfill Gas
M	Metres
M	Million, Mega
Mass	Mescoscale Atmospheric Simulation System
MBT	Mechanical Biological Treatment
MCT	Marine Current Turbines Ltd.
MJ	Mega Joule
MWe	Megawatt (electrical)
MWhe	Megawatthour (electrical)
MWht	Megawatthour (thermal)
MSW	Municipal Solid Waste
Mt	Million Tonnes
MVA	Mega Volt Amps $\equiv$ MWe
NCAR	Nat. Center for Atmospheric Research (US)
NCEP	Nat. Center for Environmental Prediction (US)

NDVI	Normalised Differential Vegetation Index
NI	Northern Ireland
NIFS	Northern Ireland Forest Service
NIE	Northern Ireland Electricity
NPK	Nitrogen, Phosphorous, Potassium Mineral Group
NW	A grouping of waste authorities in the North West of Northern Ireland
η	Electrical conversion Efficiency (varies 0.25 – 0.4)
OSI	Ordnance Survey Ireland
OSNI	Ordnance Survey Northern Ireland
OPD	Ocean Power Delivery Ltd.
P	Power Flux (wave)
PJ	Peta Joule
PSO	Public Service Obligation
REFIT	Renewable Energy Feed in Tarriff
R^2	Coefficient of Determination
RDF	Refuse Derived Fuel
REPS	Rural Environmental Protection Scheme
RMS	Root Mean Square
ROC	Renewable Obligation Certificate
RoI	Republic of Ireland
RVO	Recovered Vegetable Oil
SEI	Sustainable Energy Ireland
SMC	Spent Mushroom Compost
SONI	System Operator of Northern Ireland
SRC	Short Rotation Coppice
SRF	Slurry Recovery Factor; Short Rotation Forestry; Solid Recovered Fuel
SWAMP	South West Area Waste Management Partnership
tdm	Tonnes dry matter (in slurry sludge)
toe	Tonne (oil equivalent)
TWh	TeraWatthour
Tz	Zero crossing Wave Period (secs.)
UFU	Ulster Farmers Union
WACC	Weighed Average Cost of Capital
WAM	Wave Model
WTE	Waste to Energy
UK	United Kingdom

Executive Summary

1. Introduction

An All-Island Grid Study was jointly commissioned by Department of Communications, Energy and Natural Resources in Ireland and Department of Enterprise, Trade and Investment in Northern Ireland. The study examines the way in which the electrical network, North and South, might be cost effectively developed in the period to 2020 so as to facilitate the addition of further levels of renewable energy.

ESBI was awarded a contract for an element of the study which focussed on the location and quantification of the renewable resources that were likely to become available throughout the island and adjoining seas during this period. It was required that these resources should be placed in context with the existing electrical network.

At the outset, six potential portfolios of total projected generation plant were determined and the analysis focussed on the most effective manner in which these portfolios could be met. The renewable components of the six portfolios are presented in Figure 1 and Table 1 below.

A wide series of consultations were held with stakeholders North and South.

The key resources focussed upon were wind, biomass and ocean energy with their associated costs. All potential developments were mapped and ranked on the basis of levelised costs, using a discount rate of 8% over a project life of 20 years. In certain cases typical generation time series were prepared to assist the consideration of network issues.

Table 1. Renewable Generation Targets for 2020, in MWe

	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4	Portfolio 5	Portfolio 6
LFG	68	68	68	68	68	68
Biogas	73	73	73	73	206	269
Biomass	25	25	25	25	92	167
Co-Firing	104	104	104	104	104	104
Sewage Gas	4	4	4	4	4	16
Ocean Tidal	70	70	70	70	200	200
Ocean Wave	0	0	0	0	0	1400
Wind	2000	4000	4000	4000	6000	8000

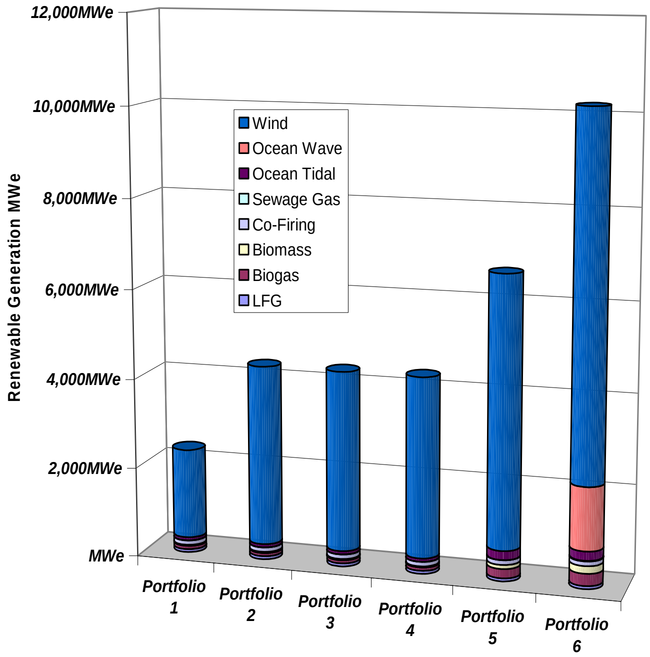


Figure 1. Renewable Generation Targets for 20020

Each resource was quantified and costed using a database system that provided for a wide range of cost items, as indicated in Table 2 below for windfarms.

Table 2. Range of Windfarm Cost Items Considered

Cost Heading	Items
Wind Farm Construction Costs	Turbine Supply, Civil, Project Management, Archaeology, Grid Compliance, Turbine Transformers, Safety, SCADA, Met Mast, Construction Insurance, Telecoms and Contingency, Environmental Impact Study
110kV Grid Connection (excluding line)	New on site 110kV station and civil costs and two end masts for 110kV overhead line or offshore-onshore interface
110kV line	110kV overhead line (Onshore Windfarm) and 110kV submarine cable and onshore interface (Offshore)
Operation and Maintenance	Land Lease, Maintenance, Electrical & Road Maintenance, Electrical Imports, Insurance, TUOS-Operations, Grid Maintenance, Rates, Management Overhead, Community Charge, Supernormal Maintenance reserve, and Contingencies

Resource evaluation followed the conventional sequence of identifying the theoretical, technical, practicable and accessible resource levels where possible.

Levelised cost tables were derived for each technology and these are arranged as levelised cost curves showing the relative ranking positions of the group of projects in each Portfolio.

2. Wind Resource

The power generation portfolios presented called for wind generation capacities of 2000, 4000, 6000 and 8000MWe respectively to be considered.

Utilising wind resource mapping, developed for different heights above ground level over the whole island and adjoining shallow sea areas, the most promising locations were identified. Account was taken of the tranche of projects that are currently operating or in the development process. Likely developments in wind turbine technology to 2020 were included.

Table 3 indicates the level of connected, contracted, grid applicant and planning applicant capacity available. These are sufficient to meet the requirements of Porfolios 1 to 4.

Table 3. Wind Penetration Levels already at Planning Phase

Category	Capacity MWe
Grid Connected/Operational	723
Contracted with Grid	795
Unsigned Grid Applicant	3241
In Planning	949
Total	**5708**

Using a kilometre grid square database, Indicative Levelised Cost was mapped and areas of least cost where highlighted. For the purpose of this study, restrictive areas were eliminated such as Natural Heritage Areas and Special Areas of Conservation and similar designated areas in Northern Ireland. The analysis provided the resultant map of Figure 2. This was married with the sites already selected in the process thus far, allowing selection of the locations of a further 292MWe and 2292MWe to meet the targets for Portfolios 5 and 6, respectively, on an all island basis.

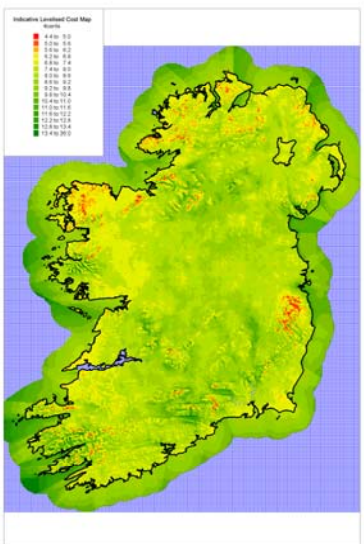


Figure 2. Plot of Levelised Cost for On-Shore Wind (red is least cost)

A table of levelised costs was drawn up for all existing projects and projects that were not already connected or contracted to connect to the system. The projects were then sorted by levelised cost in ascending order, ranging from €0.04 to €0.47 per kWh. Also documented was the current status, installed capacity and nearest 110kV node. The resultant resource cost curves were developed for each of the six portfolios.

The spatial analysis is summarised in Figure 3, in terms of potential wind penetration in selected zones of the island.

Offshore wind was also considered in the analysis but the portfolios can be fully served at the lower cost of on-shore wind.

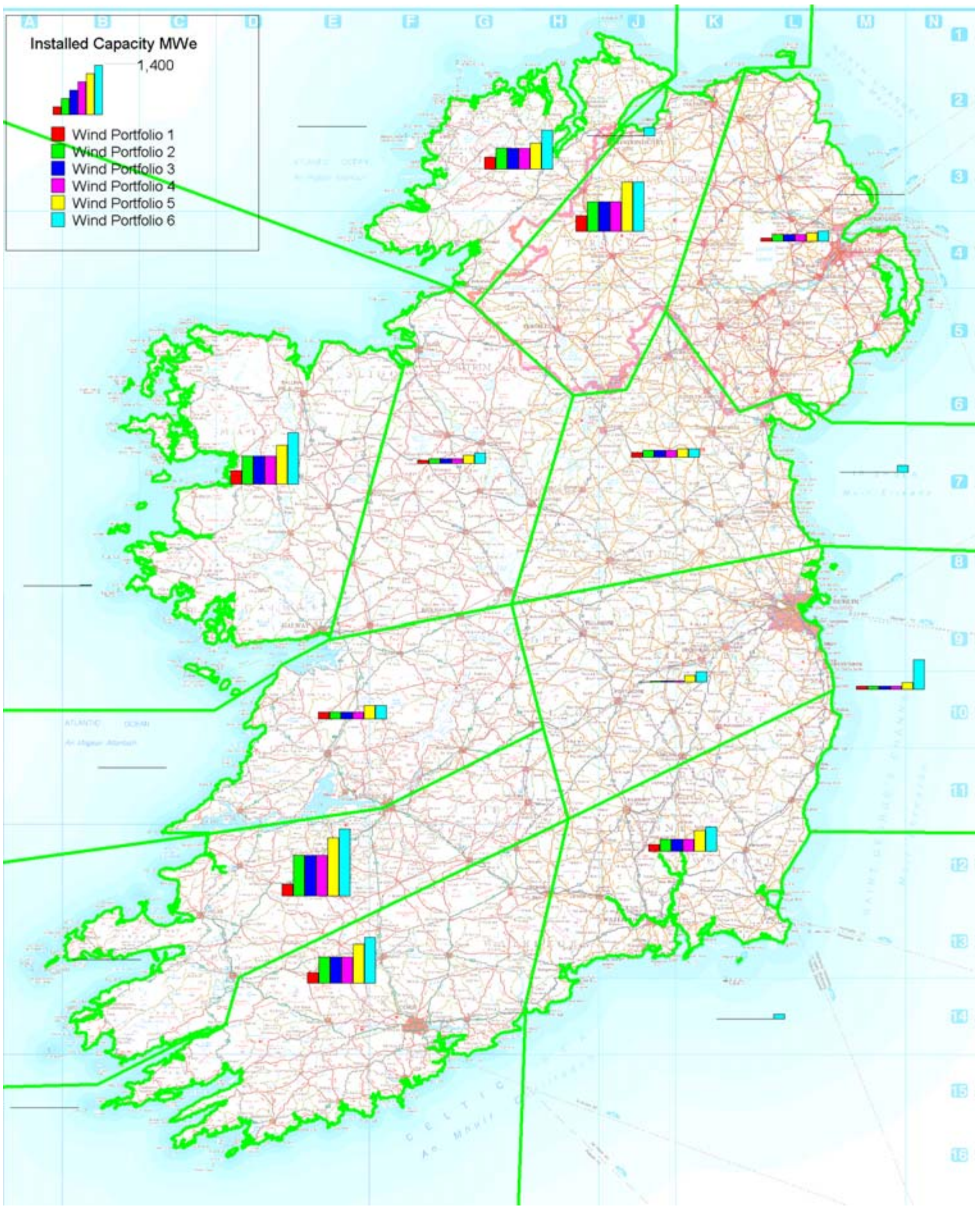


Figure 3. Level of Potential Wind Penetration within each Zone

3. Biomass Resource

The Biomass Resource is addressed under four main headings.

(a) Woody Materials including Short Rotation Coppice at New Powerplants and through Co-firing at Existing Powerplants

Demand and supply of wood is in balance at present and therefore future projections are dependent on substantial increases in levels of afforestation, short-rotation coppice (willow) and miscanthus.

Combined heat and power installations at saw mills are primarily installed to provide low-medium level heat for timber drying. The total projected capacity from this source is 12.7MWe with a levelised cost range of €0.07 – 0.09/kWhe, reflecting fuel cost and variable capacity factor for the electrical installation. This forms part of the thermal waste resource of Portfolios 1-6.

The forest/wood waste resource alone would be insufficient to make up the quota required by the portfolios and a significant dependence on short rotation coppice and miscanthus arises. This in turn highlights the possibility that the required land resource, and later the woody material itself, might be diverted to heat or biofuel production. Potential environmental constraints will also arise.

The portfolio requirements arising under this heading imply significant imports.

(b) Landfill Gas

The accessible landfill gas resource for 2020 is projected to be spread over twenty landfill sites with power ratings 0.5 – 9.4MWe, totalling 46.9MWe and levelised costs ranging from €0.04 to €0.15/KWhe. An additional twenty four sites are considered to be too small to warrant the installation cost of an energy recovery system (including network connection). At most of these sites flaring is taking place to minimise greenhouse gas effects.

In the longer term the landfill gas resource will diminish following cessation of disposal of biodegradable waste in landfill sites post 2012. According to their current waste plans, most waste management authorities plan to compost the biodegradable material rather than use it for energy production.

Therefore a shortfall arises under this heading for all power generation portfolios.

(c) Anaerobic Digestion of Sewage Sludge

Sewage gas arises from anaerobic digestion of urban sewage. So far only Dublin has installed a plant of any scale and this has a capacity of 4MW. Other smaller installations total less than 1MWe and few cities or towns are now planning the installation of such plants. Belfast incinerates the dried sewage cake produced there.

A shortfall occurs under this heading for Portfolio No. 6.

(d) Anaerobic Digestion Biogas (Wet Agricultural and Biological Municipal Wastes)

This is similar to the biogas referred to in (c) above, but its source is the much higher quantities of cattle, pig, poultry and food processing waste arising from the agricultural sector, including abattoirs, creameries and also the biological fraction of municipal waste.

The need to balance nitrogen, phosphorous, and potassium inputs to match plant needs and preserve waters and soils from overloading has stimulated consideration of these sources. Planned commercial projects dominate projected input from the wet agri waste sector and it is probable that the commercial rather than small scale sector will drive energy recovery via anaerobic digestion, particularly in Republic of Ireland. All such facilities require to successfully negotiate the planning approval process and the only projects recognised in this study are those that have already embarked on that process.

The target of 73MWe installed by 2020 for Portfolios 1 to 4 can be met at levelised costs ranging from €0.09 to €0.25 per kWh.

A shortfall arises under this heading for portfolios 5 & 6, notwithstanding the estimated size of the practicable resource. This study has concluded that a maximum of 91MW of total installed capacity can be achieved at levelised cost range €0.09 to €0.46 per kWhe.

4. Ocean Energy Resource

Ocean energy is treated under wave energy and tidal energy.

(a) Wave Energy

In recent years there has been considerable progress made in mapping the Irish wave climate from an energy perspective using both buoy and satellite measurements. In parallel the development and testing of floating wave power converters has progressed and production machines are becoming available. Undoubtedly much developmental work remains to be done but it is now possible to project average annual and seasonal performance characteristics for wave farms as for windfarms.

Portfolio No. 6 calls for 1400MWe of wave capacity in 2020 and this is met using eleven wave farm segments located off the coasts of counties Mayo, Galway, Clare and Kerry. Each segment was labelled as indicated in Table 4, mapped as in Figure 4, potential converter installations were assessed and levelised costs derived including all offshore and onshore grid facilities. The results range from €0.10 to €0.15 per kWhe, as illustrated in Figure 5.

Table 4

Projected Links between Wave Farms and 110kV Stations

Name	alled Capacity MWe	110kV Station	evelised Cost €/kWhr
North West A	154	Tawnaghmore	€0.108
North West B	140	Bellacorrick	€0.104
North West C	154	Castlebar	€0.107
West A	112	Dalton	€0.111
West B	112	Cloon	€0.112
West C	112	Galway	€0.110
West D	98	Ennis	€0.147
South West A	140	Tralee	€0.107
South West B	126	Oughtragh	€0.106
South West C	140	Knockearagh	€0.107
South West D	112	Ballylicky	€0.107

Figure 4

Potential Wave Farms on West Coast

and Associated 110kV nodes

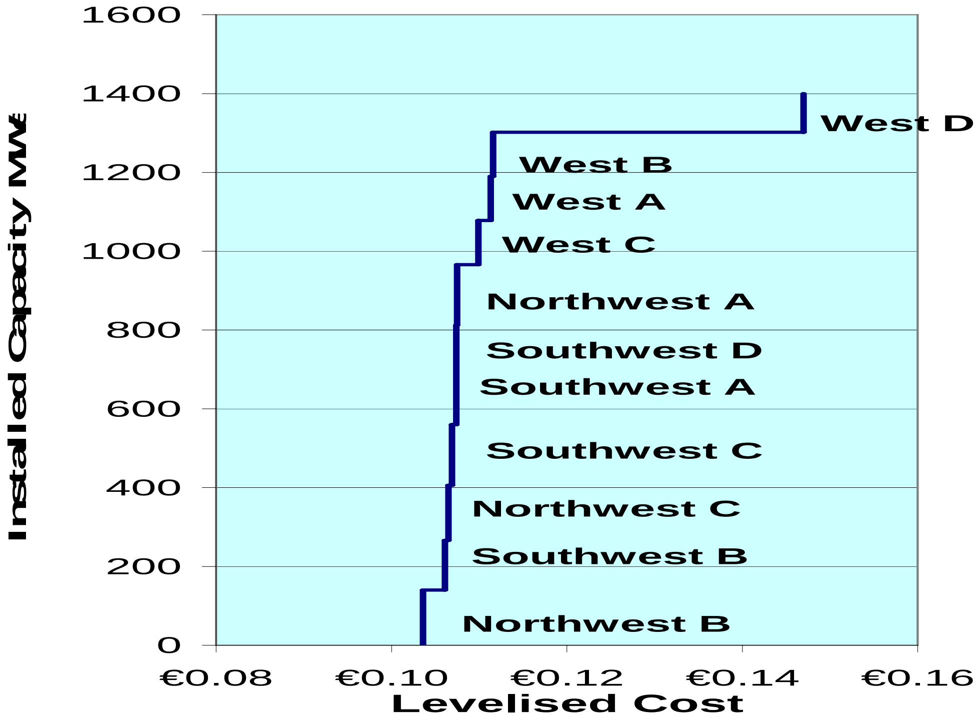


Figure 5. Resource Cost Curve for Potential Wave Farms

(b) Tidal Energy

The best tidal resource off the Irish coast is that in the North Channel between Scotland and Northern Ireland. To exploit this, tethered 'second generation' floating converters will be necessary and development of these is proceeding but slowly.

Portfolios 1 to 4 require the availability of 70MWe of installed capacity and it is envisaged that this could be met by 'first generation' installations at relatively high levelised cost, from €0.22 to €0.25 per kWhe. However Portfolios 5 and 6 would require an additional 130MWe of tidal capacity which realistically would require the installation of successful 'second generation' converters at the lower levelised cost range of about €0.10 per kWhe.

5. Small Hydro Resource

This has been quantified but it does not contribute measurably to Portfolios 1-6 and is not considered further.

6. Conclusions

The distribution and probable extent of the respective renewable energy resources have been quantified in the context of meeting a set of six generation portfolios to the year 2020. Corresponding levelised cost ranges have been identified.

(1) The major part of the windpower resource can be served by 5700 MW associated with windfarms that are at some point in the planning phase or already in operation. The remaining portfolio ‘least cost’ requirements have been identified and projects mapped by an analysis of wind resource, landuse, land roughness and grid. The projects were then sorted by levelised cost in ascending order, ranging from €0.04 to €0.47 per kWh and the resultant resource cost curves were developed for each of the six portfolios

(2) Although off-shore wind was considered in the analysis, all of the portfolio requirements were met by lower cost on-shore wind.

(3) A significant shortfall occurred in the biomass resource.

(4) For anaerobic digestion, a maximum of 91MW of total installed capacity can be achieved at levelised cost range €0.09 to €0.46 per kWhe. Landfill gas is identified at twenty sites at levelised cost range € 0.04 to € 0.15.

(5) Combined heat and power installations at saw mills are primarily installed to provide low-medium level heat for timber drying. The total projected capacity from this source is 12.7MWe with a levelised cost range of €0.07 – 0.09/kWhe.

(6) Demand and supply of wood is in balance at present and therefore future projections are dependent on substantial increases in levels of afforestation, short-rotation coppice (willow) and miscanthus.

The portfolio requirements arising under this heading imply significant imports, even for cofiring at existing plants.

Competition is developing between potential land uses that reflect biofuel production for transport, afforestation for the timber industry and, and short rotation coppice and miscanthus, for heat and electricity production. This is brought into sharper focus by the requirements of extensification and biodiversity and the prospect of a return to grain production.

(7) Up to 1400MWe of wave capacity in 2020 was considered and this is met using eleven wave farm segments located off the coasts of counties Mayo, Galway, Clare and Kerry at levelised cost ranging from €0.10 to €0.15 per kWhe.

(8) The best tidal resource off the Irish coast is that in the North Channel between Scotland and Northern Ireland. To exploit this, tethered ‘second generation’ floating converters will be necessary and development of these is proceeding but slowly. The levelised cost range would be about €0.10 per kWhe. First generation technology could be deployed at more than twice the levelised cost of second generation.

1 Introduction

1.1 All Island Grid Study

The All Island Grid Study is the first comprehensive assessment of the ability of the electricity transmission network ("the grid") on the island of Ireland to absorb large amounts of electricity produced from renewable energy sources.

On July 25th 2005 the then Department of Communications, Marine and Natural Resources in the Republic of Ireland and the Department of Enterprise, Trade and Investment in Northern Ireland jointly issued a preliminary consultation paper on an all-island '2020 Vision' for renewable energy. The paper sought views on the development of a joint strategy for the provision of renewable energy sourced electricity within the All-island Energy Market leading up to 2020 and beyond, so that consumers, North and South, continue to benefit from access to sustainable energy supplies provided at a competitive cost.

It is within the context of the All-island Energy Market Development Framework agreed by Ministers and the undertaking to develop a Single Electricity Market that consideration was given to how the electricity infrastructure on the island might best develop to allow the maximum penetration of renewable energy.

A working group was established to specify and oversee the undertaking of studies that would provide more detailed information on the above issues. The working group recommended an "All Island Grid Study" comprised of 4 work-streams detailed below.

- Workstream 1 is a resource assessment study.

- Workstream 2 investigates the extent to which electricity generated from renewable energy sources can be accommodated on the grid system with regard to variability and predictability.

  This work study comprises two stages:

  (a) an initial high level modelling study to determine the portfolios to be studied.

- (b) a detailed modelling study of the impact of renewable generation on grid operation, costs and emissions.

- Workstream 3 looks at the engineering implications for the grid, in terms of the extent and cost of likely network reinforcements to accommodate the specified renewable inputs.

- Workstream 4 uses the outputs of earlier work streams to investigate the relative economic impact and benefits of various renewable generation levels for society as a whole. It also investigates the impacts on various stakeholder groups. It is the summary report which presents high-level results for policy makers.

1.2 Methodology

In carrying out this project six lines of approach were used by ESBI International:

(1) A wide ranging series of consultations was undertaken with relevant parties North and South to develop an understanding of the different issues and motivations that affect the respective stakeholders. This also served to identify sources of information that the latter considered to be important in formulating a balanced approach to the issues involved.

(2) Acquisition and review of the reference documentation.

(3) Review and where necessary extension of ESB International's own internal and external reports, atlases and similar documentation relating to the renewable energy resources and state-of-the-art conversion technology envisaged as being commercially available during the period to 2020.

(4) Collection and presentation of the relevant energy resource information on a comprehensive geographical information system database covering the whole island and adjoining seas on a one square kilometre level of resolution. Development of report and conclusions in the context of the scenarios established at the outset by others then followed with the results being passed to the respective consultants responsible for Workstreams 2b, 3, 4 of the project.

(5) Development of levelised resource/cost curves as a basis for ranking the relative attractiveness of the different resource types.

1.3 Report Format

The report quantifies Ireland's renewable energy resources having potential for commercially viable feed into the electrical network in 2020 under the headings of:

- Wind
- Biomass
- Ocean (Wave)
- Ocean (Tidal Current)
- Cocombustion.

The sections of the report are arranged accordingly with back-up detail provided in the respective appendices.

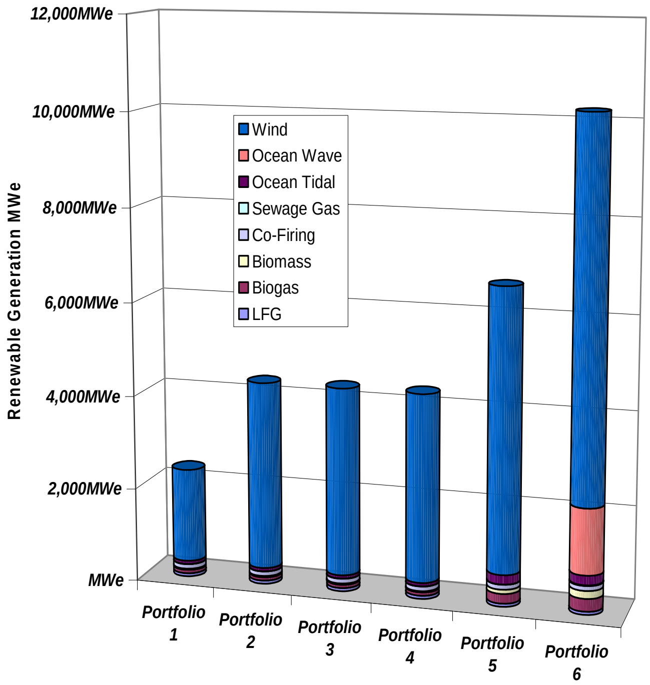
Resource evaluation follows the conventional sequence of identifying the theoretical, technical, practicable and accessible resource levels where possible.

The input material for the levelised cost projections is developed in the appendices. Where larger cocombustion projects are concerned estimates are made on an individual basis. Levelised cost tables are provided for each technology and these are arranged as levelised cost curves showing the relative ranking positions of the group of projects in each Portfolio.

1.4 Renewable Penetration Portfolios

Workstream 2a provided the Study with a set of six high level (originally 5) portfolios of generation mix for the whole island. Figure 1.1 shows the 2020 levels of renewable penetration envisaged for the six variants.

Figure 1.1 Renewable Generation Targets for 2020, tabulated and plotted for each Portfolio



	Portfolio 1	Portfolio 2	Portfolio 3	Portfolio 4	Portfolio 5	Portfolio 6
LFG	68	68	68	68	68	68
Biogas	73	73	73	73	206	269
Biomass	25	25	25	25	92	167
Co-Firing	104	104	104	104	104	104
Sewage Gas	4	4	4	4	4	16
Ocean Tidal	70	70	70	70	200	200
Ocean Wave	0	0	0	0	0	1400
Wind	2000	4000	4000	4000	6000	8000

2 Wind Energy

2.1 Definition

The Irish wind resource has been extensively mapped (onshore and offshore) in recent years resulting in the production of atlases for both the Department of Enterprise, Trade & Investment (NI) and Sustainable Energy Ireland (ROI) giving mean annual wind speeds and directions at different heights above ground or sea level (Ref. 35 & 36). Trends in the sizes of wind turbine for onshore and offshore application have been factored into projected wind farm sizes and groupings to make up the postulated wind power portfolios suggested at the outset of the project. These are discussed in Appendix 1.

Each square kilometre of accessible terrain or sea area has assets in terms of its annual wind conversion potential and liabilities in terms of its distance from the existing network (at 110kV level) and the capital cost of development. Thus it is possible to rank groups of sites in order of economic preference to make up the targeted portfolios. This is discussed in more detail in the following section where the results obtained have been tabulated.

More detailed material on the development of both wind atlases is contained in Appendix 7, including a detailed description of the methodology and conclusions reached in studies completed in 2003 and 2004 for the Republic of Ireland and Northern Ireland by ESB International / TrueWind Solutions. For the purpose of this study the atlases formed the basis of the analysis carried out and fortunately provided descriptors of the wind climate in a structure that allowed the derivation of the Technical resource which, to date, had not been previously determined.

A determination of the technical resource resulting from the wind resource, described in terms of annual energy yield, is best achieved using the frequency distribution of both the wind speed and directional components of the resource. Both these descriptors of the raw wind resource were calculated during the course of development of both wind atlases.

2.2 Primary References

The primary sources of references are: Ref 35, 36, 53, 54 & 66.

2.3 Technological State of the Art

Before the technical resource could be estimated an analysis of which type of reference energy converter would be envisaged at different stages over the time frame of consideration, 2006 to 2020 was necessary.

Following a review of current and future technology and consultation with major wind farm developers in both NI and ROI it was agreed that machines of the following ratings would be commercially available and operational up to 2020.

Table 2.1

Projected Evolution of Wind Turbine Technology 2006 to 2025

	Onshore		Offshore	
Year	Rating (MWe)	Machine Spacing (m)	Rating (MWe)	Machine Spacing (m)
2006	2	400	3.6	312
2010	3	450	3.6	312
2012	3	450	3.6	312
2015	4.5	570	4.5	342
2020	4.5	570	7	432
2025	7	720	7	432

Wind turbine generators of 2MWe, 3MWe and 4.5MWe rating are currently commercially available on the open market and the manufacturers' published power curves which were considered typical of such size machines were selected and utilised in the calculation of the technical resource. Table 2.3 lists the manufacturers and respective make and models used.

Table 2.2

Commercially available Wind Turbine Generators

Power Rating (MW)	**Manufacturer**	**Model**	**Rotor Diameter (m)**
2	Vestas	V80	80
3	Vestas	V90	90
3.5	GE Wind	GE3.6s offshore	104
4.5	Enercon	E-112/45.114	114

Currently however, there does not yet exist a 7MWe wind turbine generator. Therefore, a typical 2MWe power curve was scaled to reflect the likely performance characteristics of the future technology. As the rated power output of a wind turbine is related to the turbine blade diameter it was also possible to project the turbine dimensions which in turn influenced the spacing between generator units.

Using the blade diameters of the four machines described in Table 2.3 it was calculated that the average swept area of rotor per MW capacity was 2,315m^2 with a standard deviation of only 142m^2. Using this and projecting up, a 7MWe wind turbine would have a rotor diameter of approximately 144m.

A spacing of five times rotor diameter between the wind turbine generators for onshore application and three times rotor diameter for offshore was applied in each scenario. This approach reflects industry standard to minimise wake induced turbulence effects between turbine units as a result of the air flow through the rotor. It also reduces the resultant energy reduction due to the array effects in a multi-unit wind farm.

As the study model is set up to analyse 1km grid squares, it was necessary to determine, using the minimum unit spacing requirement, the number of wind turbines that could potentially be accommodated within a square kilometre for each type of machine.

Using this number with the selected power curves for each of the wind turbine generators and the reconstituted wind speed frequency distribution, it was then possible to calculate the gross annual energy production per kilometre grid square.

Although this calculation considered the impact of the topographical and surface roughness implications (inherent in the raw wind data), it did not consider the array, electrical, availability, high wind hysterisis, blade fouling and icing, substation maintenance or utility downtime losses. Since the number of grid squares were prohibitively high, it was not possible to run specialist wind farm energy calculation software such as WindPro (53) or WAsP (54) to calculate the net expected energy production for every square. Therefore, a sample of grid squares was selected and a determination of the losses in each category was made. This provided a generic set of factors that could be applied to the gross energy production figures calculated for each grid square to account for the aggregate expected loss for each type of wind turbine generator. Table 2.4 below indicates the loss assigned to each category.

Table 2.3 Typical Industry Accepted Energy Losses Associated with Multi-unit Wind Farms

Type	**Loss**
Array*	7.1%
Electrical Efficiency	3%
Availability	3%
High Wind Hysteresis	0.2%
Blade Fouling & Icing	0.5%
Substation Maintenance	0.2%
Utility Downtime	2%
Total	**16%**

**The estimation of a typical array loss was determined by reviewing detailed energy production analysis for a number of wind farms as conducted for clients of ESB International.*

The total 16% loss was then applied to the previously calculated gross energy production to give the net expected long term annual electrical energy production for each of the kilometre grid squares.

2.4 Basic Assumptions

The following are the main assumptions made in this study in the deployment of up to 8000MW of wind energy.

- It is assumed that the methodology of the Irish Wind Atlas 2003 and the Northern Ireland Wind Atlas 2004, based on model runs of the MesoMap system modified following a corrective procedure using real measurements from a number of meteorological wind measurement stations and privately owned tall towers is representative of the likely long term wind climate at 75m above ground/sea level.

- It is assumed that the power curves obtained for a number of commercially available wind turbines are accurate and reflect actual performance levels to be expected from respective machines.

- It is assumed that by applying across the board a loss of 16% to the calculated gross annual energy to account for wake, internal electrical, blade fouling, substation maintenance and ultility downtime losses results in a reasonable estimate of the expected net annual energy yield from each of the models square kilometres of ground surface area.

- It is assumed when deploying wind turbines in the spatial domain that turbine spacings of five rotor diameters can be applied in the case of onshore development and that a spacing of three rotor diameters can be applied in the offshore case.

- Although wind turbines rated at 4.5 to 5MW are now currently commercially available it has been assumed that by 2020, wind turbines with a rated generating capacity of 7MWe will be available on the market with rotor diameters of 144m.

- It is assumed that all applicants for grid connection supplied by both ESB National Grid and Northern Ireland Electricity have an equal probability of obtaining a connection to the grid. The basis of filtering out most likely successful candidates is based on the Indicative Levelised Cost calculated at the location of each of the candidate's wind farms.

- It is assumed that, in the case of candidates who have applied for grid connection, the amount of export power stipulated in the application will actually be availed of when connecting to the grid.

- It is assumed **purely for filtering purposes in this study**, that no spatially predicted onshore developments will occur in areas designated as being any of the following:
    - Special Areas of Conservation
    - Natural Heritage Areas
    - Areas of Special Scientific Interest
    - Areas of Outstanding Natural Beauty
    - National Nature Reserve

- It is assumed that any offshore developments will occur in areas offshore where water depth is less than 20m.

2.5 Resource Availability

2.5.1 Method for Existing Project Allocation within Portfolios

Before any predictive spatial distributions could be made it was necessary to determine the location, installed capacity and estimated annual energy production from existing projects. In this case, the term ‘existing projects’ enveloped projects that were already operational or, had obtained grid connection contracts, had applied for a grid connection contract, had been granted or had applied for planning permission.

In the case of the Republic of Ireland, it was not realistically possible to obtain information on existing projects via the interrogation of local authority planning databases. This was mainly due to the fact that each local authority maintained its own database, structured to meet its own requirements, thus a standard query could not be formulated to extract the required information from the 27 local authority databases.

In the absence of this data for the Republic it was decided to approach the issue from the aspect of grid connection information. Eirgrid is the responsible body for the grid connection of wind farms in the Republic of Ireland and, together with ESB Networs, supplied to the Study a listing of all connected, contracted and applicant wind farms in the Republic as well as indicative information on the (likely) location of connection to the 110kV system.

In the case of Northern Ireland, the Department of Environment (Planning Service) has a central office that considers all projected wind farm developments requiring connection to the 110kV system and so was in a position to supply a listing of all granted and applicant developments within its jurisdiction. Northern Ireland Electricity (TSO/DSO) subsequently supplied a listing of all connected projects, those contracted and applicants for grid connection and when married with the listing from the DOE gave a fully complete picture of the current situation in Northern Ireland.

All available wind farm information was collected into a single database and, using the coordinates supplied, the complete set was mapped using a Geographical Information System. Information attributed to each wind farm included the following:

- Wind Farm Name
- Installed Capacity
- X Coordinate (Easting)
- Y Coordinate (Northing)
- Current Status
- 110kV connection node.

2.5.2 Spatial Distributions

Workstream 2a provided the study with a set of six high level (originally 5) portfolios of generation mix for the whole island. Table 2.4 lists the 2020 levels of wind penetration envisaged for the six variants.

Table 2.4 Wind Generation Portfolios Resulting from Workstream 2A

	Total Installed Capacity
Portfolio 1	*2000MWe*
Portfolio 2	*4000MWe*
Portfolio 3	*4000MWe*
Portfolio 4	*4000MWe*
Portfolio 5	*6000MWe*
Portfolio 6	*8000MWe*[1]

[1] It was decided by the Study Working Group that the wind penetration level of 8000MWe in Portfolio 6 should be made up of 7000MWe of onshore wind farms and 1000MWe offshore.

To meet these six portfolios a summation was made of the capacities of connected and contracted wind farms in both the ROI and NI. This exercise resulted in a total wind generation capacity of 1520MWe for the island. Thus a projected shortfall of 480MWe arose on the 2000MWe target of Portfolio 1 (Table 2.5).

Table 2.5

Penetration Levels using Known Projects - Wind

	Installed Capacity Achieved	Shortfall
Portfolio 1	2000MWe	-
Portfolio 2	4003Mwe	-
Portfolio 3	4003Mwe	-
Portfolio 4	4003MWe	-
Portfolio 5	5708MWe	292MWe
Portfolio 6	5708MWe[2]	2292MWe[3]

To make up this shortfall and the larger shortfalls implied in meeting Portfolios 2 to 6, it was decided to apply a ranking to the remaining unsigned grid applicants (ROI) and undecided planning applicants (NI) in an effort to prioritise the projects that were most likely to come to fruition.

2.5.3 Future Project Projections

For the case of projects that have contracts for connection in both the Republic of Ireland and Northern Ireland it has been assumed that these projects will indeed be installed in the near future. It was decided to rank remaining listed projects at the stages of grid and planning application so as to determine their likely chances of actually being on the generation portfolio by 2020.

A method of assessing the remaining land and sea cover that would combine wind resource and cost so as to identify the best potential areas of the island for the future development of wind energy was also required. The principles of levelised cost were seen as the most appropriate way of making this determination.

Levelised cost is an indicator used to compare two or more like projects from a cost perspective to highlight the least cost option on a cost per kWhr produced over the life of the project. As the study is focussed upon the formation of a single electricity market for the island of Ireland this approach appeared to be most appropriate as it does not consider the likely revenue stream offered for each kWhr produced and as such is completely independent of the current market discrepancies between ROI and NI.

As it would be prohibitively time consuming to perform a detailed cost analysis on each and every kilometre grid square, only the key, easily identifiable, attributes would be used to determine an indicative levelised cost level for each square.

[2] Includes 85.2MWe of capacity offshore

[3] Requires 1374.5MWe of onshore and 917.5Mwe of offshore to meet the study group's revised Portfolio 6 target of 7000MWe onshore and 1000Mwe offshore.

To avoid possible future confusion, the term levelised cost, which is the primary ingredient for resource cost curves, was altered for this purpose to ILC (Indicative Levelised Cost) and is calculated using the following equation.

$$ILC = \frac{NPV_{Costs}}{NPV_{Output}}$$

where,

NPV_{Costs} = Net Present Value of all costs associated with the project including up front capital expenditure and running operational and maintenance costs discounted back to present value using a predefined discount rate, and

NPV_{output} = Net Present Value of the annual energy production from the wind farm using the same predefined discount rate.

The resultant ILC represents the unit (kWhe) cost over the entire life of the project in today's money and is heavily dependant on the discount rate applied in the equation.

The discount rate applied in this case was 8%. The reason for using this rate, was the same reason used in developing the resource cost curves for Onshore Wind, Landfill Gas and Solar Thermal outlined in "Renewable Energy Resource: Ireland to 2010 and 2020" (Ref. 12). The discount rate of 8% is made up of a risk free rate with a risk premium attached to reflect investment in energy projects. The weighted average cost of capital (WACC) as derived by the CER in the Best New Entrant (BNE- Ref. 66) assumed a cost of debt of 4.63% real and a pre-tax cost of equity of 12.44%. Under a typical debt equity ratio of 70/30 with an equity Beta of 1.83 the WACC was 7%. This would not necessarily hold through for renewable projects where the level of risk would be considered higher than in the case of conventional generation and where financiers therefore would demand a higher WACC. For this reason, in the case of wind technology the discount rate was increased further to 8%.

On assessment of the database structure within the geographical information system it became evident that the following key attributes (Table 2.6 below) could be directly extracted from, or easily calculated for each of the grid squares.

These attributes combined with the cost assumptions of the later tables 2.7 & 2.8 taken from a small number of actual costings for medium to large wind farm developments provided a generic costing model for each square kilometre of interest.

Table 2.6

Key attributes used in the determination of the Indicative Levelised Cost for each km square in the GIS database

Attribute	Relevance to the Indicative Levelised Cost
Installed Capacity	No. and rating of Wind Turbine Generators to be installed
Annual Energy Yield	Calculated from the wind resource, this would give a long term average of the potential energy yield from the installation (kWe)
Centroid of 1km Grid Square	These two sets of coordinates provide an indicative distance to the nearest connection point, which in turn has a cost implication for the site.
Location of nearest available 110kV station	

2.5.4 Wind Energy Cost Headings

The cost headings and unit costs used as inputs in developing the indicative levelised costs of the projected wind farm installations are given in tables 2.7 & 2.8.

Table 2.7

Indicative levelised Cost input cost assumptions (Mid 2006)

for the Development, Operations and Maintenance

of Medium to Large Wind Farm Projects

Item	Unit	Cost €k
Wind Farm construction Costs – Onshore	Per installed MWe	1,233
Wind Farm construction Costs – Offshore	Per installed MWe	2158
110kV Grid Connection Assets - Onshore (ROI -excluding Line)	Per Wind Farm	3480
110kV Grid Connection Assets – Offshore (R0I - excluding Line)	Per Wind Farm	5,480
110kV line Onshore (ROI)	Per linear km distance to 110kV Station	198
110kV Cable Offshore (ROI)	Per linear km distance to 110kV Station	1,431

Item	Unit	Cost €k
110kV Grid Connection Assets - Onshore (NI -excluding Line)	Per Wind Farm	3,763
110kV Grid Connection Assets – Offshore (NI - excluding Line)	Per Wind Farm	4,569
110kV line Onshore (NI)	Per linear km distance to 110kV Station	162
110kV Cable Offshore (NI)	Per linear km distance to 110kV Station	1,066
Annual O&M (ROI & NI)	Per installed MWe	51.9

The following table (Table 2.8) details the cost items included under each of the category headings in Table 2.7 above.

Table 2.8

Items included under each Cost Heading for the Purpose of ILC - Wind

Cost Heading	Items
Wind Farm construction Costs – Onshore	Turbine Supply, Civil, Project Management, Archaeology, Grid Compliance, Turbine Transformers, Safety, SCADA, Met Mast, Construction Insurance, Telecoms and Contingency, Environmental Impact Study
Wind Farm construction Costs – Offshore	Turbine Supply, Civil, Project Management, Archaeology, Grid Compliance, Turbine Transformers, Safety, SCADA, Met Mast, Construction Insurance, Telecoms and Contingency, Environmental Impact Study
110kV Grid Connection Assets - Onshore (excluding Line)	New on site 110kV station and civil costs and two end masts for 110kV overhead line
110kV Grid Connection Assets - Onshore (excluding Line)	New offshore 110kV station and civil costs and onshore 110kV offshore-onshore interface
110kV line Onshore	110kV overhead line
110kV Cable Offshore	110kV submarine cable and onshore interface
Annual O&M	Land Lease, Maintenance, Electrical & Road Maintenance, Electrical Imports, Insurance, TUOS-Operations, Grid Maintenance, Rates, Management Overhead, Community Charge, Supernormal Maintenance reserve, and Contingencies

2.5.5 Ranking of Sites

Marrying the Indicative levelised Cost value calculated for each grid square with the grid applicant and planning applicant information allowed for the ranking of the remaining sites giving the least cost sites priority when deploying the spatial distributions up to 8000MWe for Portfolio 6.

The following table (Table 2.9) indicates the level of connected, contracted, Grid applicant and planning applicant capacity available.

Table 2.9 - Wind Penetration Levels under each Category

Category	Capacity MWe
Grid Connected/Operational	723
Contracted with Grid	795
Unsigned Grid Applicant	3241
In Planning	949
Total	**5708**

2.5.6 Predicted Remaining Spatial Distribution

Using the kilometre grid square database mapped in terms of Indicative Levelised Cost (Figure 2.1) areas of least cost where highlighted using a simple query within the geographical information system. Eliminating restrictive areas such as Natural Heritage Areas and Special Areas of Conservation and similar designated areas in Northern Ireland leaves the user with a resultant map that, when married with the sites already selected in the process thus far allows for the selection of a further 292MWe and 2292MWe to meet the targets for Portfolios 5 and 6 respectively (Figures 2.4 and 2.5) on an all island basis.

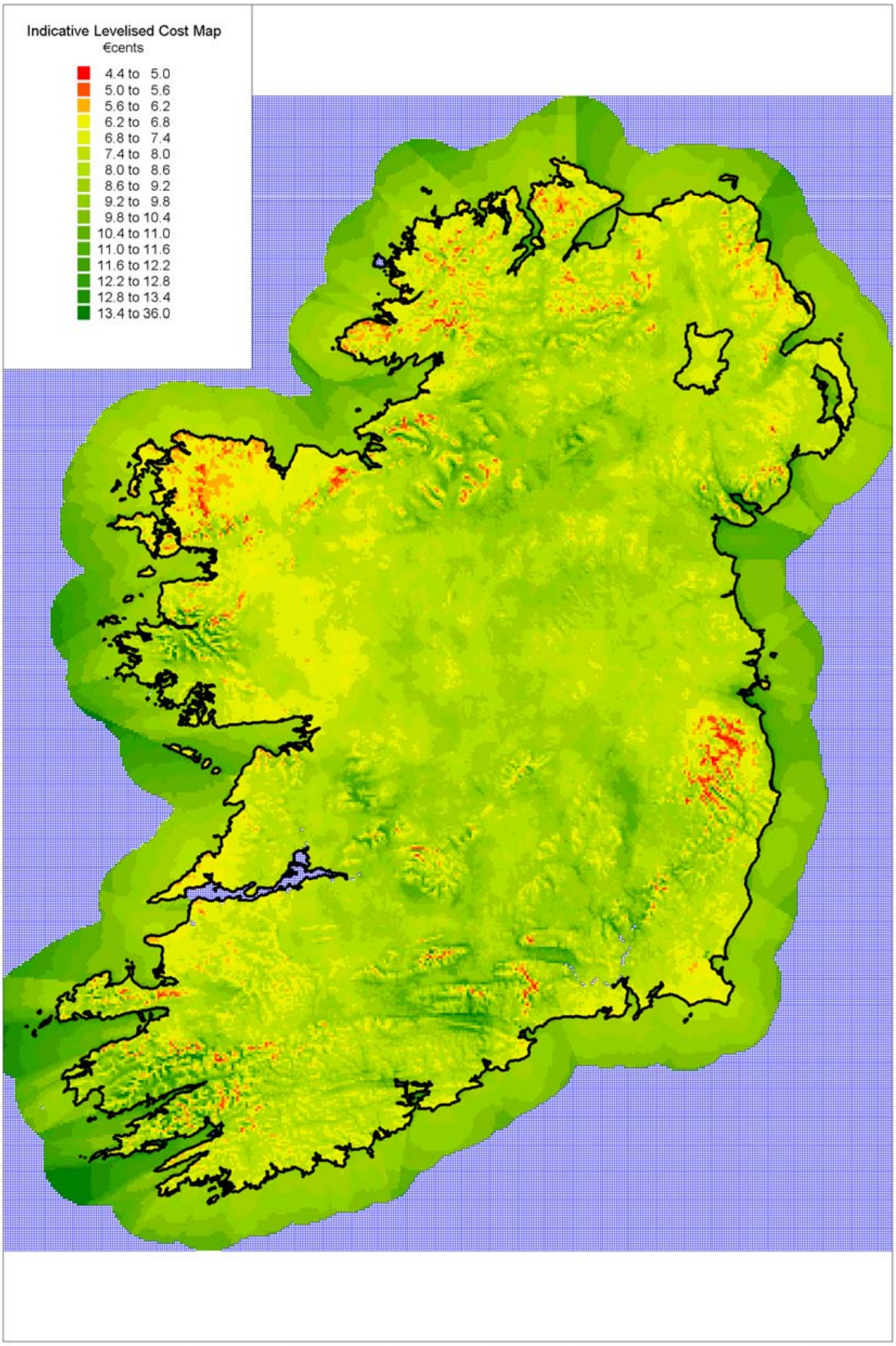


Figure 2.1

Indicative Levelised Cost Map of the Island

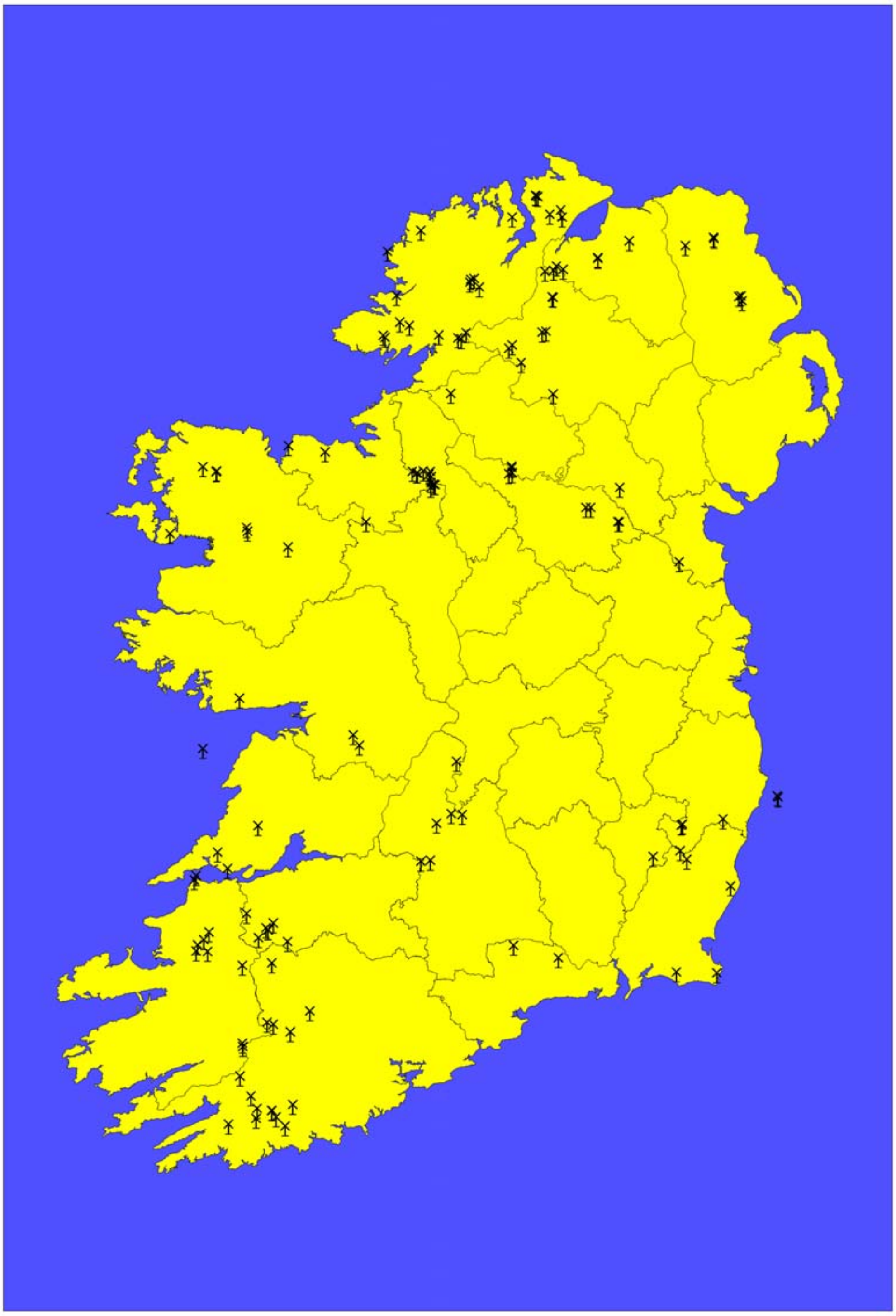


Figure 2.2

Wind farms spatially distributed to meet Portfolio 1 (2000MWe)

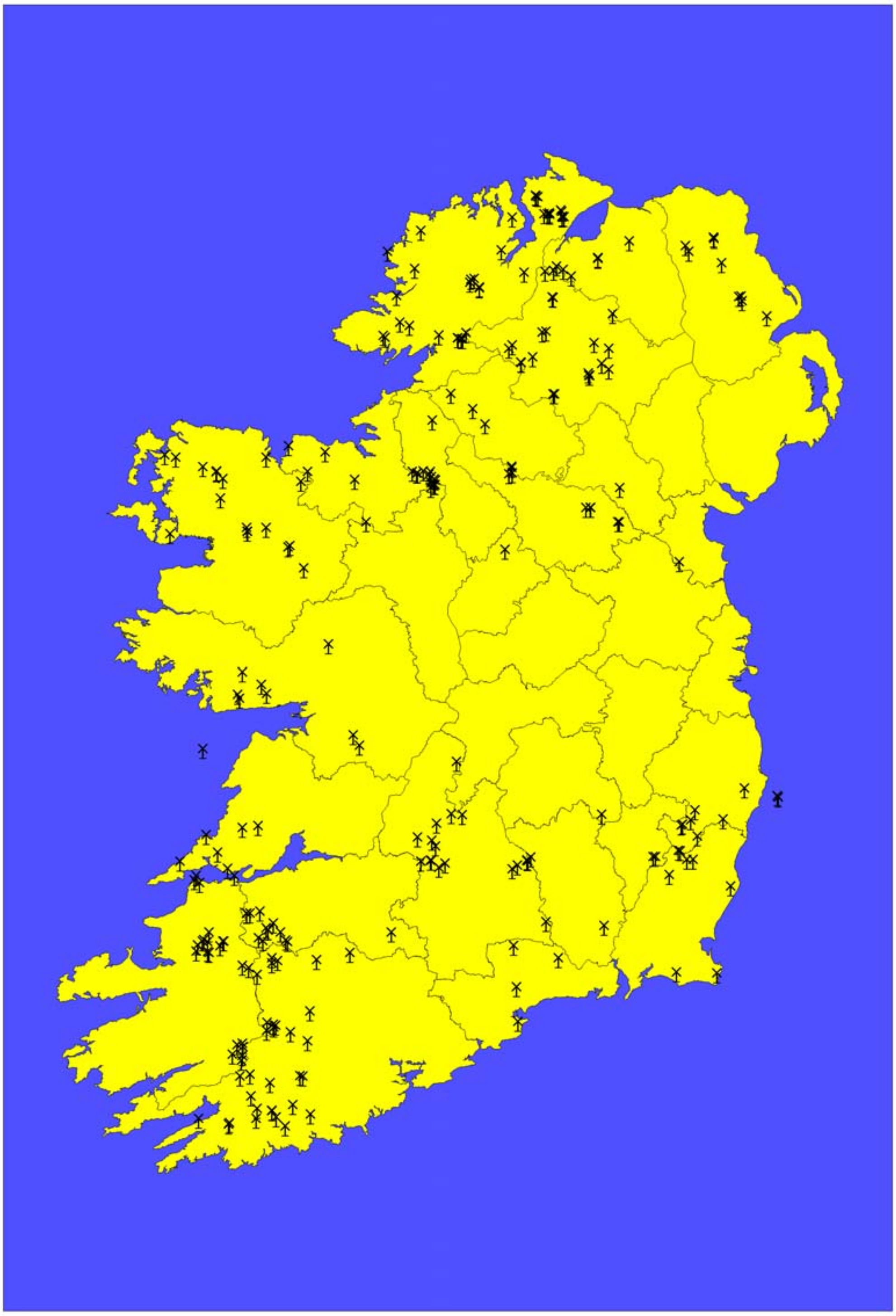


Figure 2.3

Wind farms spatially distributed to meet Portfolios 2, 3 & 4 (4000MWe)

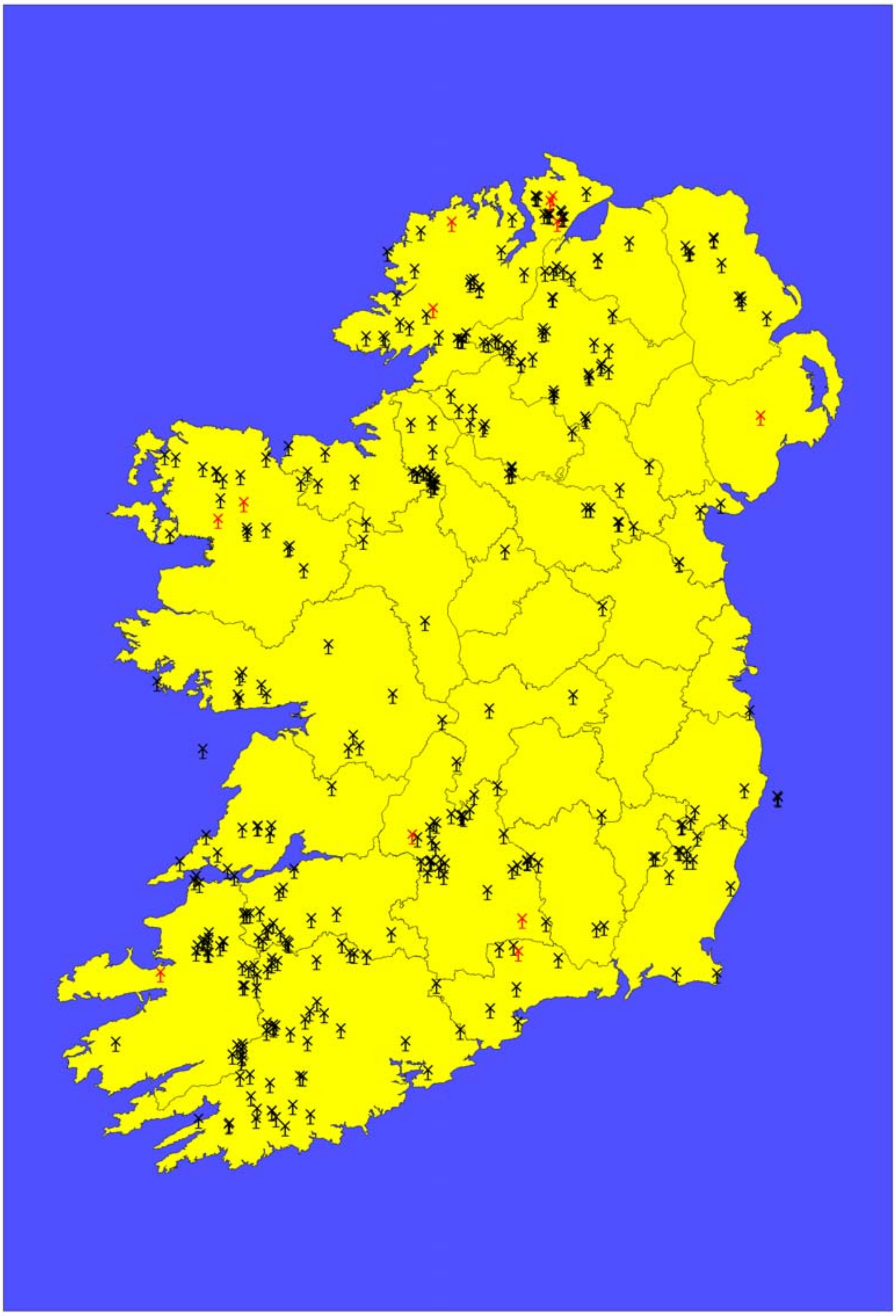


Figure 2.4

Wind farms spatially distributed to meet Portfolio 5 (6000MWe)

(Red Markers indicate predicted site locations)

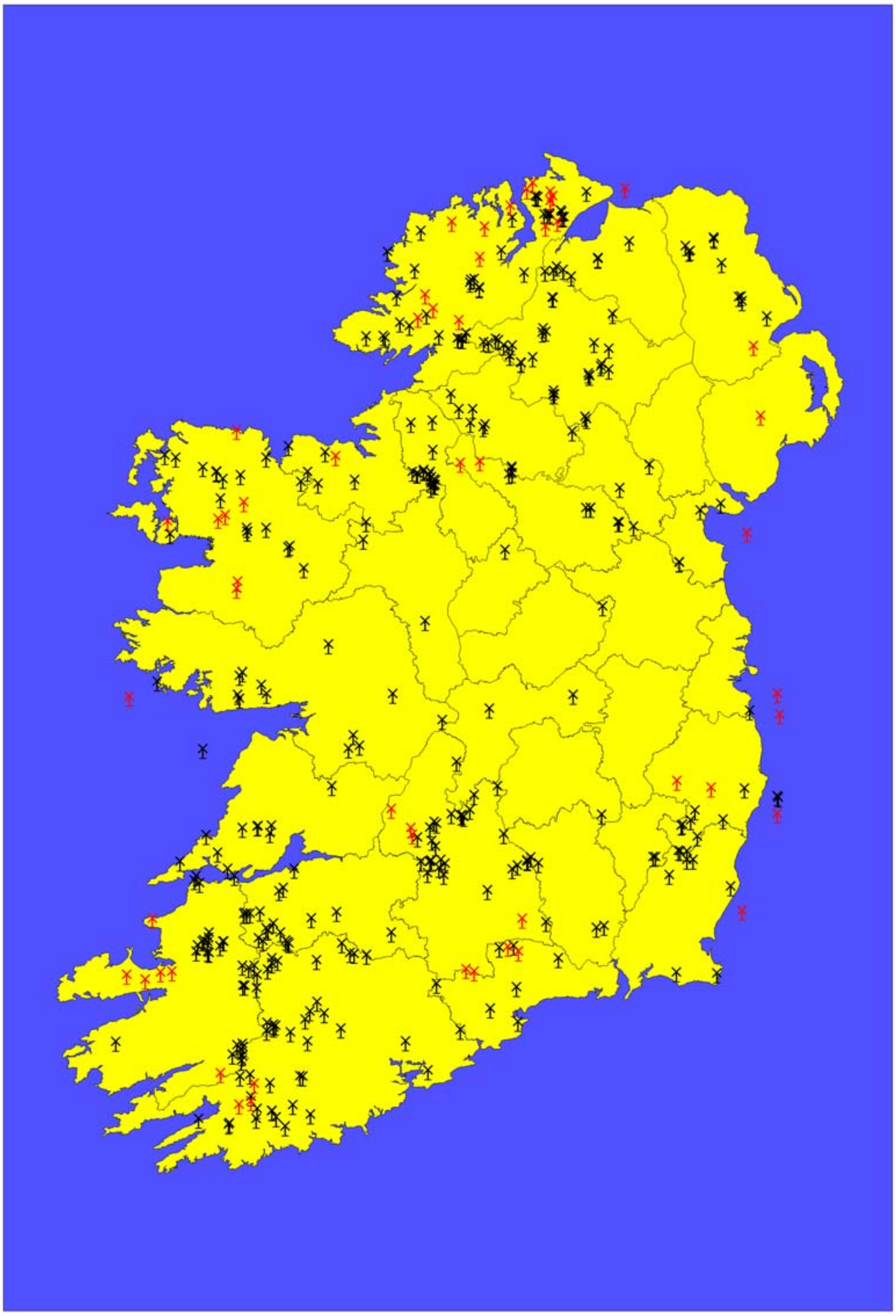


Figure 2.5

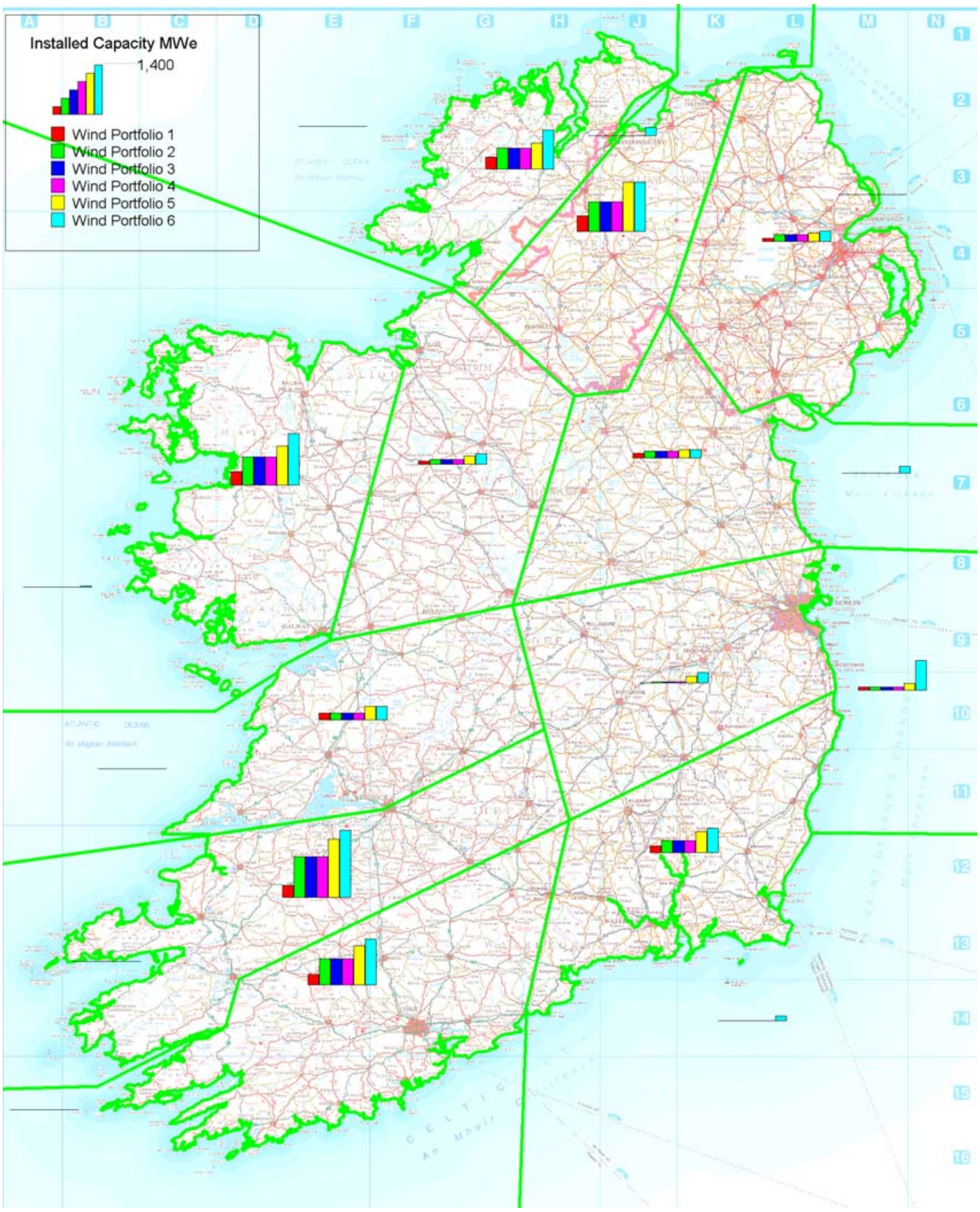
Wind farms spatially distributed to meet Portfolio 6 (8000MWe)

(Red Markers indicate predicted site locations)

2.5.7 Final Spatial Distribution

Figure 2.6 indicates the level of wind penetration for each portfolio within selected wind farm zones.

Figure 2.6 Level of Wind Penetration within each Wind Farm Zone to meet Portfolio Requirements



2.6 Cost

Each resultant portfolio was looked at in more detail and a full analysis of realsitc cost assumptions was made. In making refinement to the costings, categories of wind farm types were made using the grid connection requirement independent to each individual project. The following table illustrates the wind farm category heading under which each project was assigned.

Table 2.10

Wind Farm Categories

Category	Installed Capacity MW	Distance To Connection km	ROI Onshore 20kV	ROI Onshore 38kV	ROI Onshore 110kV	NI Onshore 33kV	NI Onshore 110kV	ROI Offshore 110kV	ROI Onshore Extension
A	< 20MW	< 20km	X						X
B	< 35MW	< 35km				X			
C	< 40MW	< 35km		X					X
D	< 110MW	All			X		X	X	X

2.6.1 Wind Turbine Construction Costs

Following a review of recent turbine inquires and construction budgets for wind farms under construction, a cost of €1.233m per MW installed for onshore development and €2.158m per MW for offshore development has been assigned to the construction capital cost of each of the wind farms. This cost includes the following items:

- Turbine Supply
- Civil, Project Management
- Archaeology
- Grid Compliance
- Turbine Transformers
- Safety
- SCADA
- Met Mast
- Construction Insurance
- Telecoms
- Planning & Environmental Impact Study
- Contingency

2.6.2 Annual Operations and Maintenance

The assigned annual operations and maintenance cost for each of the onshore wind farm projects is €51,900 per MW for ROI and €40,000 per MW for NI. The offshore cost values are €104,000 and €80,000 per MW for ROI and NI respectively.

The headings covered by these values are as follows:

- Land Lease
- Maintenance
- Electrical & Road Maintenance
- Electrical Imports
- Insurance
- TUOS-Operations (ROI only, NIE capitalise this cost in the connection)
- Grid Maintenance
- Rates
- Management Overhead
- Community Charge
- Supernormal Maintenance reserve
- Contingencies.

2.6.3 Grid Connection Costs

Under each of the wind farm categories as described in Table 2.10 above the following costs have been assigned to each connection type.

Table 2.11 Grid Connection Costs

Republic	
Onshore 20kV Connection MEC 20MW up to 20km	€1,305,000 + (€45,000 x Line Distance)
Onshore 38kV Connection MEC 40MW up to 35km	€2,385,000 + (€95,000 x Line Distance)
Onshore 110kV Connection MEC 110MW	€3,805,000 + (€180,000 x Line Distance)
Onshore Wind Farm Extensions	€325,000
Offshore 110kV Connection	€5,805,000 + (€180,000 x Onshore Line Distance) + (€1,360,000 x Offshore Line Distance)

Northern Ireland	
Onshore 33kV Connection MEC 35MW up to 35km	€2,209,300 + (€73,218[4] x Line Distance)
Onshore 110kV connection MEC 110MW	€2,701,40 + (€297,000[5] x Line Distance)

2.6.4 Levelised Cost

Using the estimates of construction, O&M and grid connection costs calculated for each of the projects and combining these with the annual energy yield for each project, a table of levelised costs was drawn up for all projects that were not already connected or contracted to connect to the system (1519MWe).

The projects were then sorted by levelised cost in ascending order, ranging from €0.04 to €0.47 per kWh and the resultant resource cost curves were developed for each of the six portfolios as shown in Figure 2.7.

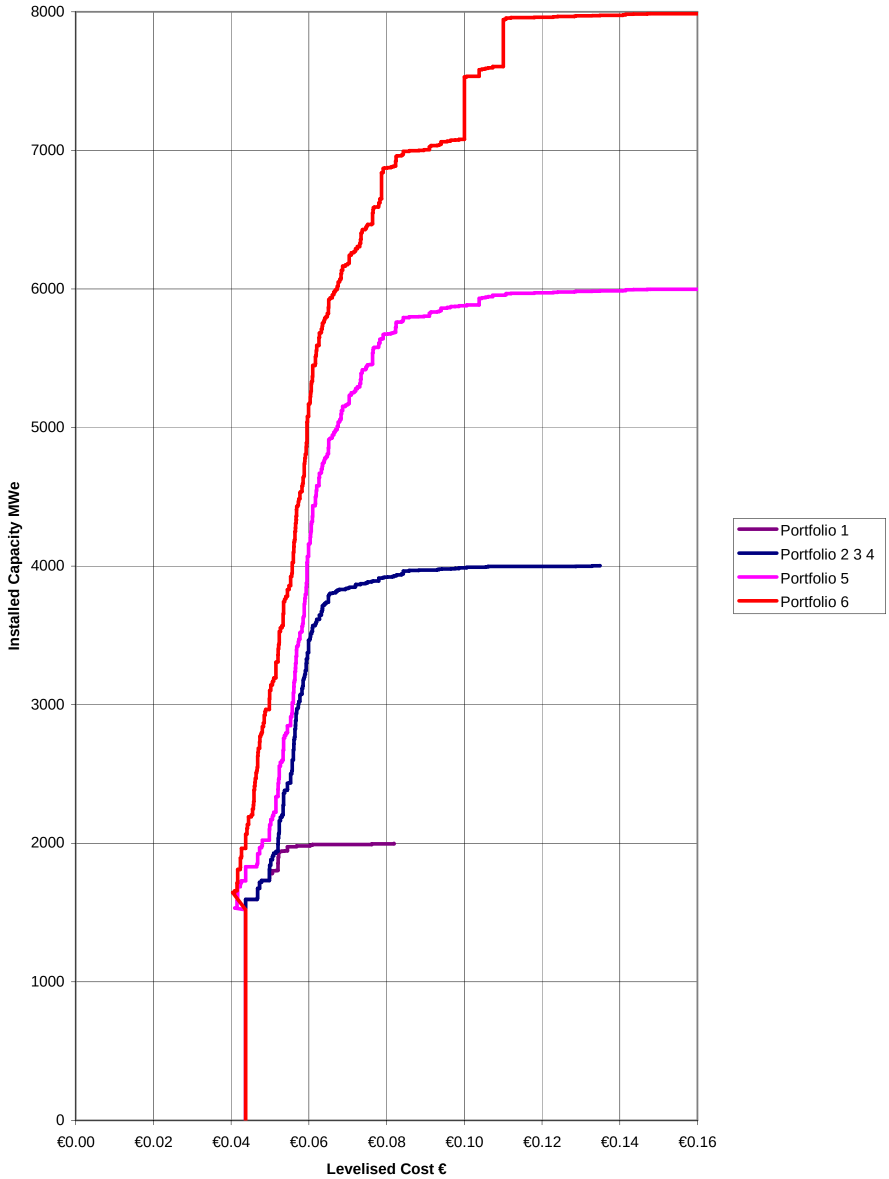
Tables A7.7.1 – A7.7.4 in Appendix 7 list the resultant wind farms and give their reference number, current status, installed capacity and nearest 110kV node to meet the targets set out for Portfolios 1 to 6.

Table A7.7.5 ranks the windfarms by levelised cost and states the current status.

[4] Includes €13,752/km for O&M of line. This cost is capitalised and not a project life cost.

[5] Includes €148,500/km for O&M of line. This cost is capitalised and not a project life cost.

Figure 2.7 - Resource Cost Curve Portfolios 1 to 6



It is noted that each of the resource cost curves do not climb at the same rate in reaching the targets set out by work stream 2a. The reason for this disharmony is that in Portfolios 1 to 4, no predicted site locations were used. Some predicted sites have lower levelised costs than the known sites and this gives rise to the step cost reductions for Portfolios 5 and 6 at 1518MWe.

2.7 Conclusions

The accessible resource can be extracted from Appendix 7, Tables A7.7.1 – 4A7.7.4 to give penetration levels of 2000MWe, 4000MWe, 6000MWe and 8000MWe respectively, with levelised cost estimates for each individual project presented in Table A7.7.5 and in Figure 2.7 above.

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3 Biomass Resource

3.1 Introduction

Biomass has been broadly defined as ‘materials of biological origin that can be used as a source of energy’. Thus covers a wide variety of materials and seven different conversion pathways are of interest in the context of this report. These include:

1. Municipal Solid Waste Incineration to yield heat/electricity
2. Biological Municipal Waste (BMW) Anaerobic Digestion (AD) at landfills to yield landfill gas
3. BMW processing via Mechanical Biological Treatment (MBT) and in vessel AD to yield biogas fuel for heat/electricity
4. Sewage Sludge AD to yield biogas fuel for heat/electricity
5. Wet Agri/food waste AD to yield biogas fuel for heat/electricity
6. Dry Agri Waste Incineration
7. Woody Crop/residues combustion, gasification, pyrolysis to yield heat/electricity.

In addition cocombustion of woody material with peat/coal for electricity production is discussed in Section 6.

It is worth bearing in mind that there are other biomass feedstocks and other uses to which they can be put e.g. transport biofuel or syngas production but these above will be of primary interest from the electricity generation perspective. While most of the above conversion paths focus on the treatment of wastes, conversion of purpose grown material is included. It is also possible to enhance the performance of anaerobic digestion processes by mixing several different feedstocks together. The biomass resource is discussed with reference to these conversion methods below.

3.2 Costs

The levelised costs per KWhe of the biomass resource are based on projected capital and operating/maintenance cost inputs as detailed in this section and in the corresponding appendix.

Table 3.1

Key Attributes used in the Determination of Indicative Levelised Cost of Biomass fed Energy Projects

Attribute	Relevance to Indicative Levelised Cost
Installed Capacity	Rating of biomass fuelled installation
Annual Energy Yield	Calculated from characteristics of supplied biomass, consumption, capacity factor, efficiency
Location of Site Reference Point	The two sets of coordinates provide indicative length for overhead line to the nearest network connection point which in turn has a cost implication for the site.
Location of nearest available terrestrial 110kV station	

Table 3.2

Projected Cost Base for Development, Operation and Maintenance of Biomass Fed Projects

Item	**Description**	**Unit**	**Rate €k**
1.	Biomass Converters		
1.1	MSW Incinerator	Sum	Varies with rating of plant
1.2	LFG Installation	“	“
1.3	BMW/MBT + AD installation	“	“
1.4	Sewage Biogas	“	“
1.5	Wet AgriWaste AD Plant	“	“
1.6	Dry AgriWaste Incinerator	“	“
1.7	Woody Combustion/Gas/Pyrol.	“	“
2.	Overhead Line		
2.1	End masts	Number	Varies with rating
2.2	OH Line (Factor 1.15)	Km	Varies with rating/distance
3.	Receiving 110kV Station		
3.1	Apportioned share of Upgrade	Sum	Varies with rating
3.2	Metering	Sum	“
3.3	MV Cubicles	Sum	“
4.	Operation & Maintenance		
4.1	% of Total Capital Cost/yr	%	Varies

Refer to Appendix 10 for capital costs (excluding transmission).

Table 3.3

Items included under each cost heading (Biomass)

	Cost Heading	**Items**
1.1 1.2 1.3 1.4 1.5 1.6 1.7	MSW Incinerator LFG Installation BMW/MBT + AD Sewage Gas Wet Agriwaste AD Dry Agriwaste Incinerator Woody Combust/Gas/Pyrol.	Design/Construction/Installation of biomass fed facility in compliance with applicable specifications, codes, standards, and regulations at designated site, including waste separation system and post treatment digestate, storage or ash disposal system, access roads, laydown and parking areas.
2.	Overhead Line (Not applicable to 1.8)	33/38/110kV overhead line rated for appropriate load between end masts at generator and receiving 110kV station in compliance with TSO/DSO specification and regulatory requirements (including testing and commissioning).
3.	Receiving 110kV Station Upgrade	Provision of additional compound space, bays, busbars, founds, structures, ducts, circuits and equipment as are required to meet TSO/DSO specifications and requirements including testing and commissioning.
4.	Annual O&M	Land lease/wayleave rentals, infrastructure maintenance, electrical imports, TUOS, operations, grid maintenance, insurances, insurances, rates and levies, spares, reserves, and contingencies.

The projected all-island municipal, agricultural and industrial waste biogas resources (excluding LFG and sewage) are summarised on in Appendix 5, Table A5.6.6 showing total capacity (91MWe), relevant portfolios and levelised costs ranging from €0.10 to €0.46.

In the Republic of Ireland the planned commercial projects (Ballard and Rose Green) dominate projected input from the wet agri waste sector (and a further facility rated at 8MWe to process meat/bone meal has been proposed at Nobber, Co. Meath during finalisation of this report). It is probable therefore that the commercial rather than public or small scale private sector will drive energy recovery via anaerobic digestion in the south.

3.3 MSW Incineration

3.3.1 Definition

MSW incineration has been practised in some form on mainland Europe and elsewhere for many years. Following concerns about public health and anxiety the EU developed strict rules governing the design and operation of such plants.

This led to numerous older plants being phased out and replaced by plants having improved combustion characteristics and fitted with sophisticated flue gas clean up systems. Much attention also focussed on the separation of materials for recycling purposes at the ‘front end’ of the plant. As incinerators tend to be located near urban areas the opportunity for CHP and district heating developments is immediately apparent particularly in Northern continental areas that have prolonged winter heating needs.

Characterisation of the ash arising and secure disposal routes are a necessary part of the development process.

Incineration of the appropriate waste material has been one of the elements of government waste policy North and South and has been included in a number of regional waste plans which are listed in the following sections. Because of the differences in scale of these facilities and the likelihood that they will be provided by third parties to match local circumstances there will probably be a number of differences between individual plants.

3.3.2 Primary References

The primary sources of information used include Refs. (40, 41, 42).

3.3.3 Technological State of the Art

A fully integrated state-of-the-art waste materials plant involving energy recovery via digestion and incineration would feature the following waste processing elements:

- Raw MSW delivery reception
- Disk screens
- Iron separator (magnet)
- Shredder
- Plastic separator (trommel screen)
- Aluminium separator
- Air stover
- Fuel feed pile
- Premixing tank
- Digestor(s)
- Sludge dewatering

- Filter cake incineration
- Steam to turbogenerator or other users
- Biogas compression
- Biogas clean up, CO_2 extraction
- High quality syngas
- Flue gas clean up scrubbing
- Ash and clean up products to landfill.

Clearly economy of scale is a major factor in the specification of such plants but smaller plants featuring direct combustion instead of the digestion stage are appropriate to their particular circumstances.

3.3.4 Basic Assumptions

It is assumed that 152MW of capacity can be obtained from a number of named waste planning authorities which have included thermal treatment projects within their portfolio of waste management methods and where there is a credible prospect that these may proceed either via public/private partnership or commercial development (there are none operational at present).

3.3.5 Resource Availability

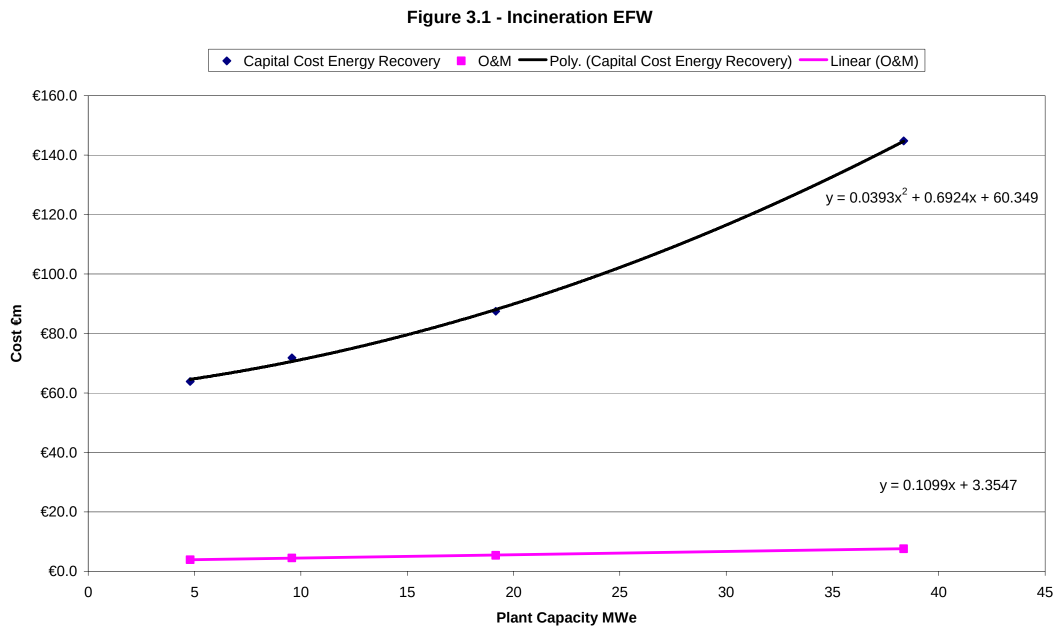
Table 3.4

MSW Incineration Resource

Name	Installed Capacity MWe	X	Y	Fuel	110kV Node	Levelised Cost € per kWhr
Belfast	43	334700	377200	Municipal Waste	Power Station West	€0.076
Dublin	60	320100	233600	Municipal Waste	Ringsend	€0.073
Cork	20	178500	64500	Municipal Waste	Haulbowline	€0.122
South East	12	269500	114500	Municipal Waste	Mungret	€0.155
North East Duleek	21	306500	271100	Municipal Waste	Platin	€0.095
South West	14	153900	154900	Municipal Waste	Waterford	€0.137

3.3.6 Cost

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in Figure 3.1 and in the corresponding appendix.



3.3.7 Conclusions

(1) Thermal waste to energy plants can reasonably be envisaged as coming on stream as follows, if the respective waste plans are implemented.

Table 3.5

Potential Municipal Waste to Thermal Energy Plant Locations (All-Island)

Location	Capacity	Date	Coordinates
Belfast	30MWe (43MWe)	2012 (2020)	Greater Belfast
Dublin	60MWe	2010	(320 100E, 233 600N)
Cork	12MWe	2010	(178 500E, 064 500N)
"	8MWe	2016	(" ")
South East	12MWe	2013	(269 500E, 114 500N) **
North East	16MWe	2012	(306 500E, 271 100N)
South West	14MWe	2013	(153 900E, 154 900N)
Total	**165MWe**		

(**) Two adjacent locations on the River Suir estuary had been identified as potential waste to energy plant sites by commercial interests in the past. For the purposes of this study only that shown is considered.

(2) It is projected that the Belfast, Dublin and Duleek (North East) installations will be developed with full separation and recovery facilities so that the fuel is residual municipal material only. (Table A5.8.2). The Dublin (60MWe) and Duleek (21MWe) facilities to be available for Portfolios 1-6 at levelised costs of €0.06 and €0.07/kWhe respectively. The Belfast plant (43MWe) would be available for Portfolios 5, 6 at a levelised cost of €0.06/kWhe.

(3) The facilities projected for Cork (20MWe), South East (12MWe) and South West (14MWe) are considered to be somewhat more uncertain but are tentatively allocated to Portfolios 5, 6 at levelised costs estimated at €0.13, €0.11, €0.10/kWhe respectively, exclusive of gate fees, heat sale possibilities etc.

3.4 Landfill Gas

3.4.1 Definition

The biological or putrescable fraction of municipal solid waste amounts to about 50% of the whole. When buried in landfills in moist conditions and lacking oxygen the process of anaerobic digestion commences and follows a predictable sequence as described in Ref. 12. A gradual build up of landfill gas occurs over time which if it is not tapped by collection pipes will gradually leak out of the landfill and escape to atmosphere.

Modern practise is to design sea bed landfills of ‘dumpling’ shape with built in piping systems to facilitate gas generation and collection. It is a requirement that at least the gas should be flared to reduce emissions from CH4 to CO2. However if the landfill is of sufficient scale the gas can be fed to a spark ignition engine/generator set and the electricity sold.

The cost of an electrical connection is a key factor and numerous sites are considered to be too small or to be generating too little gas for viability in this respect. This particularly affects older sites where much of the gas generated in the past leaked out into the atmosphere before adequate cover could be achieved. Depending on the constituents of the waste the gas may be corrosive with consequentially higher costs for engine operation and maintenance. Landfill gas utilisation is now considered to be a mature technology in the UK and the electricity produced no longer attracts the level of tariff that it did in earlier days. Various techniques such as ‘resting’ the landfill, recirculating leachate etc. are practised to increase gas yield but eventually the digesting material becomes exhausted, the pipe network provides a means of flaring any residual gas and the generator units are removed.

3.4.2 Primary References

The primary source of reference is: (Ref. 12).

3.4.3 Technological State-of-the-Art

Landfill gas technology is now considered to be relatively mature technology which is projected to have a finite life as the amount of biodegradable material going to landfill decreases. However the generating side of the technology (engine/generator) will continue to find application in other biogas fuelled systems (e.g. anaerobic digestion/gasification). Two types of landfill applications may be distinguished:

(1) those based at older landfill sites that were not specifically designed for gas utilisation and where much may have already escaped but where the scale is sufficient to justify an installation, and

(2) purpose designed landfills where gas production is maximised and piping is installed on a staged basis during the site filling period.

The overall site monitoring programme is an essential back drop to the operation with measurement of oxygen, carbon dioxide as well as methane concentrations, pressure and leachate level. Changes in carbon dioxide level can be a useful indicator of methane migration.

The LFG generation units are installed in skid mounted containers which can be moved to and from the site as gas production builds to a peak and then wanes. When the site is no longer economically viable as a producer, the piping is used to feed residual gas to flare points so that the methane component can be burned off. Management of the sequencing of production wells on a particular site is an active process (including engine condition monitoring) having regard to the variable nature of the buried materials and the sometimes highly corrosive elements that may be found in gas from particular parts of a site, where acid forming factors such as gypsum materials may occur.

3.4.4 Basic Assumptions

- According to industry sources the small size and pattern of a number of landfill sites made them uneconomic to develop for electricity production. However from an assessment of present and planned sites it is assumed that a capacity of 46.9MWe can be installed by 2020, bearing in mind that biodegradable municipal waste disposal to landfill will be phasing out (North and South) in accordance with EU Policy.
- While it might be expected that much of the biodegradable material would find its way to anaerobic digestion as desired by EU, most RoI regional waste plans focus on low technology composting as the disposal route and it is therefore assumed that this route will be followed, without energy production apart from the locations noted.

3.4.5 Resource Availability

Table 3.6

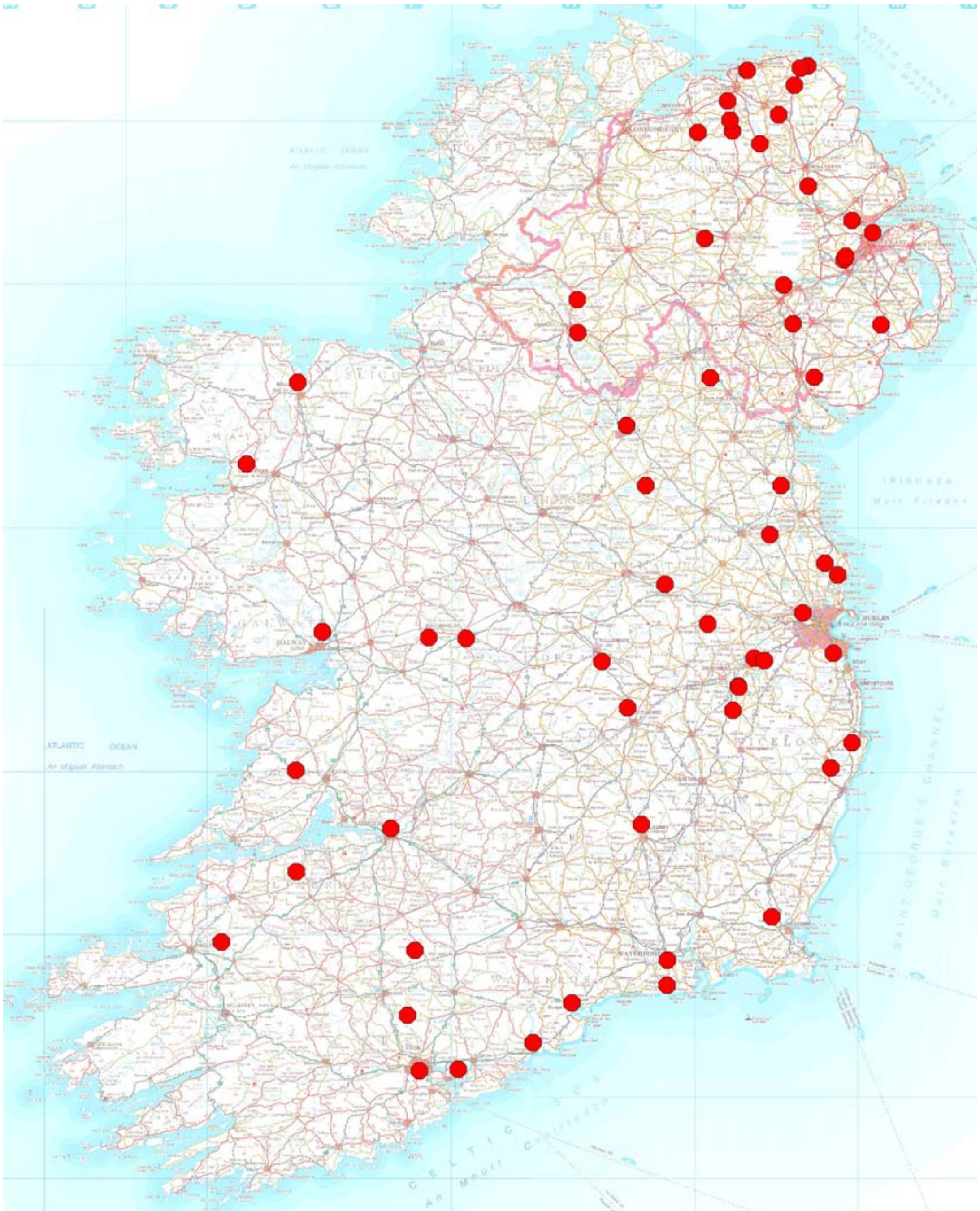
Landfill Gas Resource

County or LA	E	N	Name	Status	Installed Capacity	110kV Node	Levelised Cost €/kWhr
Cavan	244463	307793	Corranure	Closing – 2010, circa 1MW 2008-20	1	Shankill	€0.07
Clare	122400	180700	Ballyduff	Circa 1MW	1	Ennis	€0.08
Cork	168000	69600	Kinsale Rd.	2 x 1MW operational	2	Trabeg	€0.06
Dun Laoghaire	320700	223900	Ballyogan	2 x 1MW operational	2	Fassaroe	€0.06
Dublin City	309500	238600	Dunsink	1 x 1.2MW operational	1.2	College Park	€0.06
Fingal	322330	252540	Balleally	5 x 1MW operational	5	Glasmore	€0.06
Galway	132304	231560	Carrowbrowne	Closed 2001, - 1MW from 2008	1	Galway	€0.07
Galway	171418	229674	Kilconnell E. Galway (2005)	Greenstar – 1MW from 2010	1	Agannygal	€0.08
Kildare	285700	211700	Silliot Hill	1 x 1.2MW, operational,	1.2	Newbridge	€0.07

County or LA	E	N	Name	Status	Installed Capacity	110kV Node	Levelised Cost €/kWhr
Kildare	285750	211300	KTK (1999)	2 x 1.2MW operational, 1.2MW o/s	2.4	Newbridge	€0.06
Kildare	283570	202770	USK (2008)	- 1.5MW circa 2010	1.5	Stratford	€0.06
Kildare	295317	221160	Arthurstown	South Dublin (5 x 1.4MW, 2 x 1.2MW operational)	9.4	Kilteel	€0.05
Limerick	122678	143194	Gortadroma	- 1.8MW	1.8	Rathkeale	€0.06
Meath	297332	267325	Knockharly	Greenstar C - 1MW 2007-8	5.4	Platin	€0.04
Wicklow	327540	190797	Ballinagran	Greenstar - 1.5MW 2010	1.5	Ballybeg 110kV Station	€0.06
ARC21	335100	378900	Dargan Rd. (Belfast)	4MW	4	POWER STATION WEST	€0.05
ARC21	324620	368880	Mullaghglass	Start up: Nov. 06	1	LISBURN MAIN	€0.09
ARC21	327600	383400	Cottonmount	Start up: Nov. 06	2	GLENGORMLEY MAIN	€0.06
ARC21	325100	370100	Aughrim		2	LISBURN MAIN	€0.06
ARC21	338300	344950	Drumnakelly	0.8Mm3	0.5	BALLYNAHINCH MAIN	€0.15

Figure 3.2

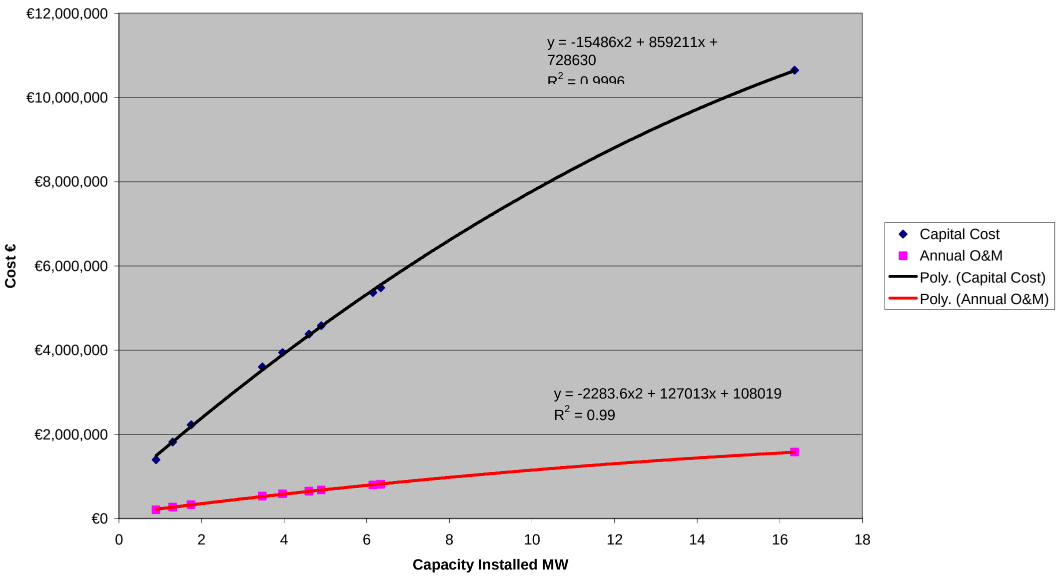
Landfill Gas Resource



3.4.6 Costs

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in Figure 3.2 below and in the corresponding appendix.

Figure 3.3 - Landfill Gas Cost Estimates



3.4.7 Conclusions

(1) The accessible landfill gas resource for 2020 is projected to be spread over twenty landfill sites with power ratings 0.5 – 9.4MWe totalling 46.9MWe and levelised costs ranging from €0.4 to €0.15/KWhe.

(2) An additional twenty four sites are considered to be too small to warrant the installation cost of an energy recovery system (including network connection). At most of these sites flaring is taking place to minimise greenhouse gas effects.

(3) In the longer term the landfill gas resource will diminish following cessation of disposal of biodegradable waste in landfill sites post 2012.

3.5 Biological Municipal Waste + MBT/AD

3.5.1 Definition

The projected amounts of biodegradable municipal wastes arising from the year 2020 in RoI are developed from DOEHLG projections to 2016, while for Northern Ireland they are derived from the projections of the regional waste planning bodies. Typically this material consists of vegetable and food waste, grass and leaves, catering waste, garden and hedge trimmings etc.

3.5.2 Primary References

The primary sources of references are: Refs. (25, 34, 40, 41, 42, 58).

3.5.3 State of the Technology, BMW MBT + AD

In general the first element in the process consists of a feedstock screening, processing and preparation stage where unbiodegradable materials, wood, metals, glass, stones, plastics etc. are screened out and rejected.

The feedstock may be then pulverised and seeded by mixing with a fraction of recirculated digestion slurry before being fed to a horizontal (Kompogas) or vertical (Valorga, Dranco) digester, where the digestion process takes place for a period of 2-3 weeks during which the charge is agitated by internal mixers (Kompogas) or programmed streams of pressurised biogas bubbles (Valorga). The biogas is drawn off at the top of the digester and stored for combustion or a feeding to a gas engine/generator unit.

The digestate that leaves the unit is dewatered and post treated aerobically to produce compost which can go to agriculture. The Kompogas digester operates under thermophilic conditions and takes the form of a horizontal cylinder (usually of steel) that can be sized to process 4-100kt of material annually. Kompogas report 29 operational plants mostly sized in the 10-24kt/yr. range in Europe and Japan. The Valorga system has been in operation for 20 years and features both mesophilic or thermophilic operation. There is little to choose between either type in terms of gas yield. Plant size is at the larger end of the scale reaching 200kt/yr. in some recent installations. The Dranco system was reported to be operational in at least nine full scale plants in Europe ranging 10-50kt/yr. in capacity. Typical gas yield is 100-150Nm^3/t of waste.

3.5.4 Basic Assuptions

- It is assumed that the emphasis in the treatment of biodegradable municipal waste will swing toward mechanical biological systems with energy recovery in the form of recovered fuel and anaerobic digestion.
- It is assumed that uncontaminated recovered wood will find its way as a low moisture content feed stock into the heat industry as chips or pellets.

3.5.5 Resource Availability

Table 3.6

Key BMW Diversion Targets for 2010, 2013, 2016 (RoI)

Year	Total BMW (t)	Recycle (t) %		Biological (t) %		Residual Requiring Treatment (t) %		Landfill (t)	
2010	2,379,516	765,050	(32.2)	338,129	(14.2)	308,904	(13)	967,433	(40.6)
2013	2,374,541	876,849	(36.9)	414,546	(17.5)	438,190	(18.5)	644,956	(27.1)
2016	2,268,731	875,371	(38.6)	442,129	(19.5)	499,762	(22)	451,469	(19.9)

These figures provide indicative envelopes of the theoretically available national biodegradable municipal waste resource for the Republic over the years to 2020. The bulk of this will arise in the vicinity of the main population centres.

Composting is very much the preferred option in the Regional Waste Plans where biological treatment is concerned and the need for adherence to specific standards is clearly understood if the large quantities of compost projected are to find acceptable end uses. Anaerobic digestion of biodegradable municipal waste is only in limited use at this stage.

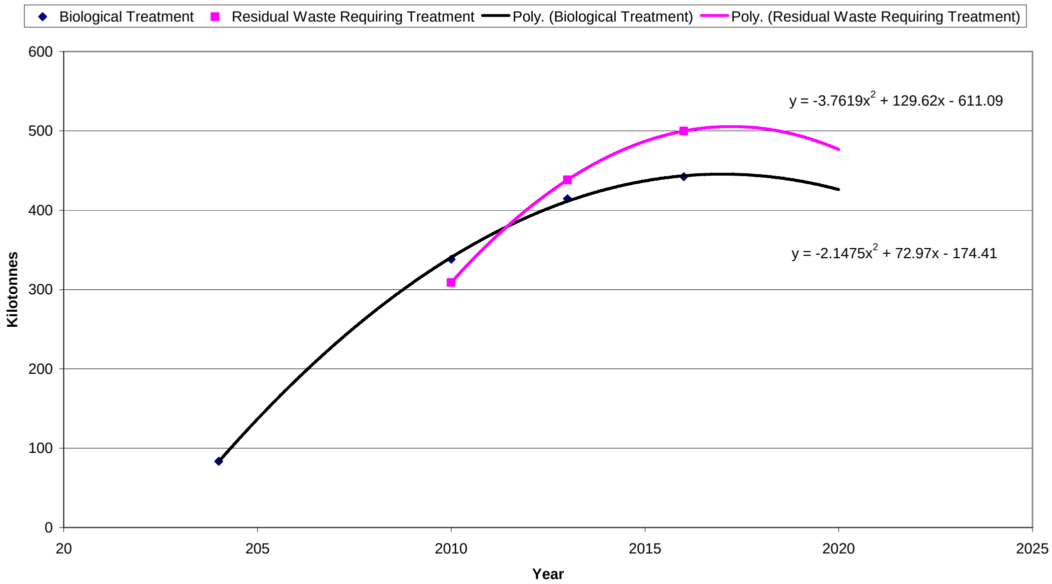
Best fit projections from Table 3.6 of biodegradable residual waste requiring treatment and that treated show tonnages of 476,550 and 425,990 respectively for 2020. (Fig. A5.1) giving feedstock for a technical electrical energy resource as follows (Table 3.7).

Table 3.7

Theoretical Electrical Energy Resource Implied by BMW Strategy (2020)

Type	Tonnage/Yr.	Treatment	Conversion Factor	Energy GWhe/Yr	Capacity MWe
Biologically Treated Waste	425,990	AD	407 kWhe/t	173.378	23.28
Wood Waste Recovery	159,280	Thermal	1166kWhe/t	169.79	22.8
Residual Waste	476,550	Thermal	714 kWhe/t	340.26	45.7

Figure 3.4 - Biological Municipal Waste Treatment Requirement (ROI)



These are national resource figures and give an overview of BMW position. The likelihood of their being achieved will depend on the availability of treatment and energy recovery facilities at key centres, the extent to which commercial and industrial stream is also catered for and the influence of gate fees, tariff levels etc.

The regional groupings that have been developed for waste management purposes by the local authorities are discussed in the Appendix with particular reference to energy recovery facilities that are included in the portfolios under the Biomass (thermal) heading.

In Northern Ireland the regional waste plans mentioned make provision for Mechanical Biological Treatment (MBT) of both residual MSW and commercial/industrial waste. They also recognise the looming problem of agricultural slurry management and the benefits of economy of scale in treatment systems.

Advanced energy recovery systems are considered to be these that produce gas using anaerobic digestion, pyrolosis or gasification of putrescible material, any one of which can form the energy recovery stage in MBT treatment. The position is summarised on Table 3.8 where thermal treatment (Belfast) and identified agricultural wet waste streams are also recognised. While the Local Authorities do not have responsibility for dealing with agricultural slurries there is logic to processing these at centralised plants where economy of scale and similar processing of the authorities own biodegradable waste streams can be undertaken at sites already owned by Local Authorities even if the plants were operated by others.

This allows the projected electrical energy resource from biodegradable municipal, commercial and a large segment the wet agricultural waste resource to be summarised in extent and location. The agricultural waste stream is discussed further in the Appendix.

Table 3.8

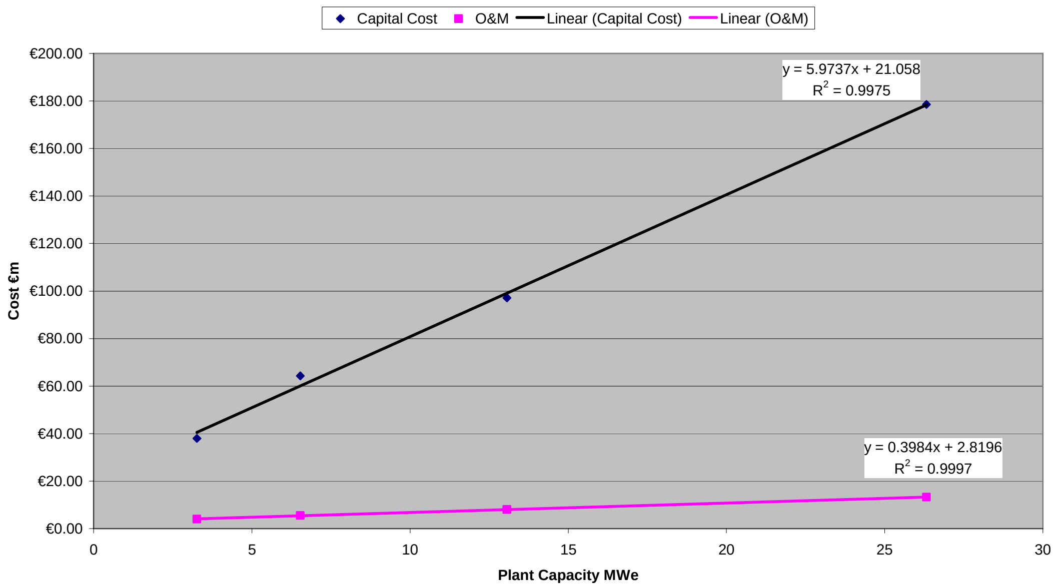
Sumary of Waste to Energy Projections for Northern Ireland

Area	**Waste Types**	**Process**	**Possible Location**	**Energy Output MWhe/Yr.**	**Capacity MWe**
NW	MSW + C & 1	MBT/AD	Derry	29711	4
	MSW + C & 1	MBT/AD	Letterloan	29711	4
	WET AG.	AD	Drumaduff	12450	0.57
	WET AG.	AD	Cross Targherty	12450	0.57
SWAMP	MSW + C & 1	MBT/AD	Aughnagun	44542	6
	MSW + C & 1	MBT/AD	Tullyvar	44542	6
	MSW + C & 1	MBT/AD	Drumnee	17550	2.4
	Wet AG.	AD	Magheraglass	8300	0.375
	Wet AG.	AD	Aughnagun	8300	0.375
	Wet AG.	AD	Tullyvar	8300	0.375
Private	Ag. Chicken Lit.	Thermal	Glenavy		24MWe
Arc 21	MSW + C & 1	MBT/AD	Cottonmount	50875	6.4
	“	“	Mullaghglass	50875	6.4
	“	“	Aughrim	50875	6.4
	“	Thermal	Belfast	320178	43
				Total	**110.865MWe**

3.5.6 Costs

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in Figure 3.4 below and in the corresponding appendix.

Figure 3.5 - Mechanical Biological Treatment & Advanced Conversion Technology Cost Estmates



The projected capital and operating costs of typical MBT/AD digestion systems are given as graphs and regression curves in Appendix 12. To these are added to transmission costs derived as a function of the distance between the projected site and nearest 110kV station.

Table 3.9 - Accessible AD from Agricultural/Municipal Waste Portfolios 1 - 6

Name	E	N	110kV Node	Installed Capacity MWe	Levelised Cost €/kWhe
Drumaduff	270742	415920	Limavady Main	0.57	€0.09
Cross Tagherty	300500	422500	Coleraine Main	0.57	€0.10
Aughnagan	313500	325500	Newry Main	0.375	€0.11
Tullyvar	226200	354200	Enniskillen Main	0.375	€0.11
Magheraglass	273200	376700	Dungannon Main	0.375	€0.12
Mullaghglass	324620	368880	Lisburn Main	6.4	€0.25
Cottonmount	327600	383400	Glengormley Main	6.4	€0.25
Aughrim	323400	371000	Finaghy Main	6.4	€0.25
Aughnagan	313500	325500	Newry Main	6	€0.28
Tullyvar	226200	354200	Enniskillen Main	6	€0.28
Derry	247500	421500		4	€0.33
Letterloan	281600	427500	Coleraine Main	4	€0.33
Drumnee	226400	342090	Enniskillen Main	2.4	€0.46
Vale Project, Ballard*	187700	106600	Barrymore	32	€0.14
Rose Green Project	213500	132500	Cahir	15	€0.15

3.5.7 Conclusions

(1) This analysis allows the projected electrical energy resource from biodegradable municipal, commercial and a segment of the wet agricultural waste resource to be summarised in extent and location. (The agricultural waste stream is discussed in detail in Section A5.6).

(2) It is concluded that MBT/AD when applied to the processing of the biological component of MSW and C+I waste in Northern Ireland will give rise to a capacity of 41.6MWe (Table A5.4.6) at levelised costs ranging from €0.25 – 0.46/kWhe (Table A5.6.5).

(3) In the Republic the emphasis in local authority treatment plans for biodegradable municipal waste has been to focus on direct composting in preference to digestion with energy recovery followed by composting of digestate.

3.6 Sewage Gas

3.6.1 Definition

Primary and secondary sewage sludge arise as settled solids from urban waste water sewage plants. As standards of quality of discharges into fresh and sea water bodies have increased (Urban Waste Water Directive) over the years the needs for improved treatment has increased but different paths are available for dealing with the resulting sludge. The largest installation in Ireland is that at Dublin (4MWe) where the sludge is anaerobically digested, dewatered, dried and granulated for use as a low quality odour free fertiliser. During the anaerobic digestion process the biogas is collected and used for electricity generation using gas engines similar to those used for biological municipal waste gas. Other options exist as the incremental cost of the electrical production equipment is significant and in some cases the gas is used simply to heat the sludge during the digestion process.

The sludge arising at the other main population centre, Belfast, is dewatered and incinerated by Water Service. Based on information gathered during production of this report it is not envisaged that there will be significant additional generation of electricity from municipal sewage sludge as the relevant local authorities have adopted other treatment paths that do not involve electrical energy recovery, sewage digesters are installed at seven towns at present.

3.6.2 Primary References

The primary source of reference is: Ref. (72).

3.6.3 Technological State of the Art

Typically incoming waste water (sewage) is initially processed by passing through fine screens to remove floating debris. Off live storm water storage tanks are provided to moderate inflow to the works or bypassing during storms. The sewage then passes through grit removal tanks where supernatant oils, fats and greases may also be removed before entering the primary settlement tanks where the primary sludge settles out out on the tank floors from which it is drawn off to a sterilising tank. The settled waste water meanwhile flows from the primary tanks to secondary tanks for biological secondary treatment. Here the waste water is oxidised with air to accelerate the biological process which results in further (secondary) sludge settlement. The secondary sludge is also fed to the sterilisation tank like the primary sludge. The water from the secondary settlement tank now flows through an ultraviolet disinfection process before return to the river.

Meanwhile the primary and secondary sludge, having been sterilised, passes to an anaerobic digestor where it is heated and allowed to digest, producing biogas. The gas is drawn off and fuels a CHP plant which can typically 50% of the energy needed to run the works.

The digestate is then dewatered and dried at high temperature to a granular form in which it can be used as an odourless pastuerised organic fertiliser on tillage and grassland.

3.6.4 Basic Assumptions

- It is assumed that apart from Dublin and some smaller centres there is little scope for further capacity above the existing 4.5MW here as other treatment methods are proposed.

3.6.5 Resource Availability

The total capacity is estimated at 4.5Mwe.

Table 3.10 - Electricity from Sewage Gas

Location	**Installed Capacity**
Dublin City	4MWe
Kildare (Osberstown)	160kWe
Clonmel	120kWe
Tralee	55kWe
Total	**4.335MWe**

3.6.6 Cost

As this plant is already connected to the sytem no costs are provided.

3.6.7 Conclusions

The present capacity as shown on Table 3.10 is rounded to 4.5MWe and is available in Portfolios 1-6. As it is already connected to the network the question of projected levelised costs does not arise.

3.7 Wet Agri-Food Waste

3.7.1 Definition

The wet agricultural waste resource is made up of cattle, pig and poultry manures and food industry wastes and residues. These have been estimated (Appendix 5) for both the Republic and Northern Ireland in some detail. When digested anaerobically at a raised temperature for 2-3 weeks these materials evolve biogas in which methane is the dominant component (- 60%) with carbon dioxide making up most of the remainder.

The process is analogous to that used in biodegradable municipal waste and sewage sludge digestion. Different animal slurries produce different levels of gas and the key issue in quantifying the accessible resource relates to selection of credible levels of slurry recovery factor for use with the respective waste streams. This in turn is influenced by the level of control or housing applied to the animals and the size and spread of different farm units.

For the purposes of this study processing levels not unrelated to those experienced in Denmark and Holland have been borne in mind but it is recognised that while intensive farming as practised in these countries is not wholly applicable to Ireland, new criteria in relation to permissible mineral levels in different soils and groundwaters, and the gradual development of operating experience with agriwaste digestor systems over the past two decades create challenges and opportunities within which electricity production is only one factor among several in considering the viability of the resource.

3.7.2 Primary References

The primary sources of references are: Refs. 37, 38, 44, 49, 50, 51.

3.7.3 Technological State of the Art

Although anaerobic digestion of sewage sludge has been applied increasingly in highly populated urban areas from about 1900 onward, followed by industrial waste digestion it is only since the1970 period that installation at farm level and centrally for the treatment of animal waste slurries has developed.

Centralised anaerobic digesters are now designed to accept a range of inputs from different sources whereas earlier types usually dealt with a single slurry type from a single source (urban, farm or industry). Codigestion usually has the merit of increasing gas generation but places higher demands on plant operators and may restrict disposal routes for the residual digestate as wastes from particular sources may not be acceptable for application to farmland.

A considerable amount of evolution has gone into the understanding and development of the well found modern anaerobic digester system which would typically possess most of the following features:

- Enclosed offloading and feedstock reception area equipped with twin reception/blending tanks, twin main storage tanks with mixers, twin macerators and feed forward pumped with tanks/vented to flare stack
- Twin heated pathogen pasteurisation tanks (70^{o}C for at least 1 hour)
- Twin temperature controlled continuously gas or mechanically stirred digesters with at least 15 days retention capacity, with wall sampling ports and 30% of volume as gas collection space at top
- Floating cover gasometer with safety system
- Heating boiler(s) and CHP unit
- Closed digestate storage tank (vented to stack)
- Digestate dewatering system and closed liquor storage tanks
- Instrument and control system
- Personnel accommodation and small test laboratory
- Tanker service area.

It can be appreciated that economy of scale, reliable supply, gate fees and other factors in addition to electricity sales must play their part in keeping a facility of this type viable even though as much as possible of the plant will usually have been prefabricated to minimise site costs.

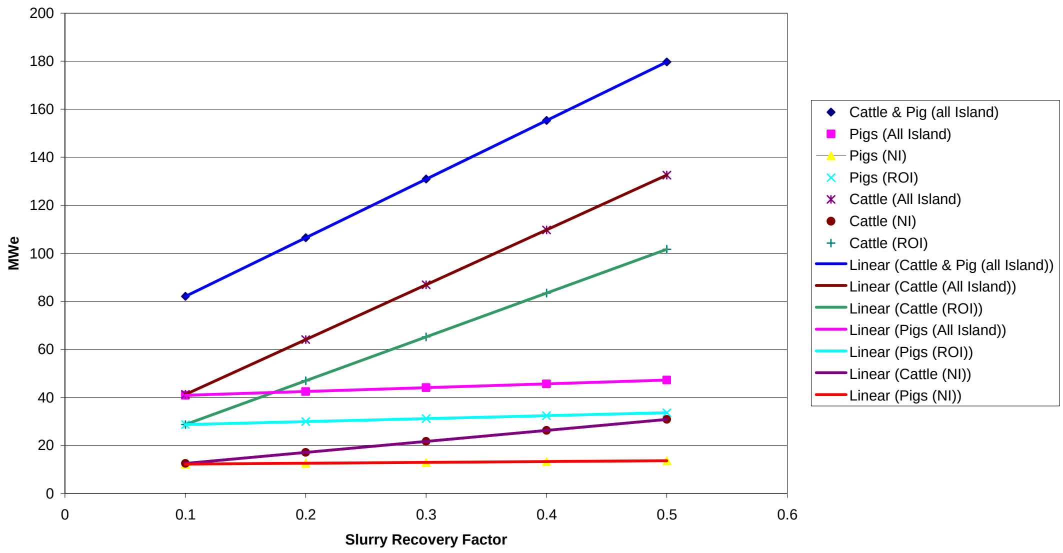
Smaller farm based systems would typically possess a single line without the duplications of the above system.

3.7.4 Basic Assumptions

- While there is a significant theoretical and technical resource arising from animal and poultry manures under this heading it is widely dispersed. There are increasing pressures for these wastes to be more closely managed on environmental grounds. Attention has focussed on pilot areas where agricultural waste and agrifood waste production coincide with potential heat loads and where central anaerobic digestion plants might be installed on the Danish model. Because of transportation costs and other constraints the scale of such plants is small individually with capacities in the range 0.5 – 1MW, which would usually be accommodated on the MV network. It was decided to focus on known commercial projects (amounting to 47MW) of a scale likely to require connection at 110kV level.
- It is recognised that there is potential for more of this type of installation but that these frequently face local opposition in respect of planning permission.

3.7.5 Resource Availability

Figure 3.6 - Sensitivity of Practicable Power Capacity (MWe) to Cattle and Pig Slurry Recovery (Food, Poultry Recovery 0.75)

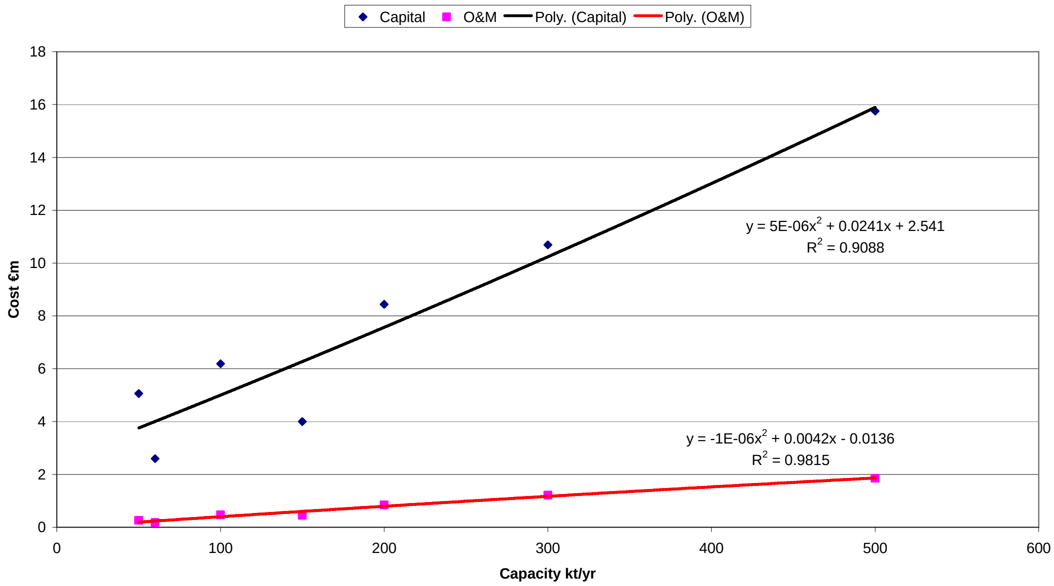


The sensitivity diagram shows the size of the practicable resource as a function of the amount of cattle or pig slurry or both recovered (between 10% and 50%) while keeping the Food and Poultry waste recovery levels at 75%. For the purposes of this report the cattle and pig slurry recovery levels are conservatively set at 10% (SRF = 0.1). The figure is applicable to the Republic or Northern Ireland or both. (Thus if 10% of the cattle and pig slurry (all island) and 75% of the food and poultry waste could be collected and digested per year it would support slightly in excess of 80MWe of plant).

3.7.6 Costs

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in Table 3.9 above and Figure 3.6 below and in the corresponding appendix.

Figure 3.7 - Agricultural Anaerobic Digestion Cost Curve



3.7.7 Conclusions

(1) The projected all island municipal, agricultural and industrial waste biogas resources (excluding LFG and sewage) are summarised on Table A5.6.6 showing total capacity (91MWe), relevant portfolios and levelised costs ranging from €0.10 to €0.46.

(2) In the Republic the planned commercial projects (Ballard and Rose Green) dominate projected input from the wet agri waste sector (and a further facility rated at 8MWe to process meat/bone meal has been proposed at Nobber, Co. Meath during finalisation of this report). It is probable therefore that the commercial rather than public or small scale private sector will drive energy recovery via anaerobic digestion in the south.

3.8 Dry Agricultural Waste

3.8.1 Definition

Certain types of agricultural waste do not readily lend themselves to energy recovery via anaerobic digestion. These include chicken litter, mushroom compost, and straw. (Broilers and breeding fowl give rise to litter (moisture content 35-46%) whereas layers and ducks give rise to slurry (moisture content circa 90%). In the Republic 64% of poultry litter production is concentrated in Co. Monaghan while a substantial tonnage also arises in Northern Ireland where its nitrogen content would require the rental of typically 21,000Ha for disposal by land spreading at a significant cost. Land spreading has been increasing in the Republic also due to a decline in the mushroom industry which took 40-70% of the material as a feedstock for mushroom compost.

Spent mushroom compost contains chicken litter wheaten straw, water and gypsum which has a poor thermal value when moist and ranks below wood chips and most other biomass when dry. Again the bulk of spent mushroom compost occurs in Co. Monaghan where the limit of disposal by land spreading has been reached.

The distribution of the straw resource is primarily centred on the south and east of the island but only wheaten straw, which occurs on a rotational basis, is considered to be in surplus.

Straw combustion requires a plant specifically designed to deal with the particular levels of corrosive elements that it contains. Its low density also results in a significant transport cost element.

3.8.2 Primary References

The primary sources of references are: Refs. 11, 24.

3.8.3 Technological State of the Art

A variety of small boilers have been used in the past to burn dry agricultural wastes with the combined objectives of waste disposal and an increasing degree of energy recovery. At the more sophisticated end of the scale various boilers with patented grates derived from industrial applications have been used with varying degrees of success. Small scale gasifiers have also been developed and in many respects this work is still ongoing. It has been found that where efficiency and durability are concerned it has been necessary to go back to basics and redesign systems specifically to deal with the chemical elements and moisture levels to be found in agricultural wastes such as straw.

In this respect separate refractory lined chambers and heat exchangers for steam production have evolved.

The bubbling fluidised bed boiler has lent itself to being scaled downward while still possessing the ability to roast the thermal value from most agricultural fuels by virtue of the high temperature thermal inertia and close contact between bed grains and fuel particles.

Examples are Eye (12.7MWe), Thetford (38.5MWe), Glanford (13.5MWe), Westfield (9.8MWe) (Poultry Litter) Ely (38MWe) (Straw). Glanford now operates on meat and bone meal. Ash from the chicken litter process forms a useful fertiliser.

3.8.4 Basic Assumptions

- Although there is scope for this type of treatment mainly focussed on chicken litter with cocombustion of other materials a preliminary project of this kind was refused planning permission in an area where it could have contributed significantly to local agricultural waste management. It is assumed that a second project this time based in Northern Ireland may be more successful and that a capacity of 24MW can be installed.
- Because of its combustion characteristics, geographic spread and competing uses it is felt that there is likely to be little attraction for commercial interests in developing a standalone straw burning plant. While it may find a use as a minor fuel component in other plants it is not assumed to contribute to biomass plant capacity.

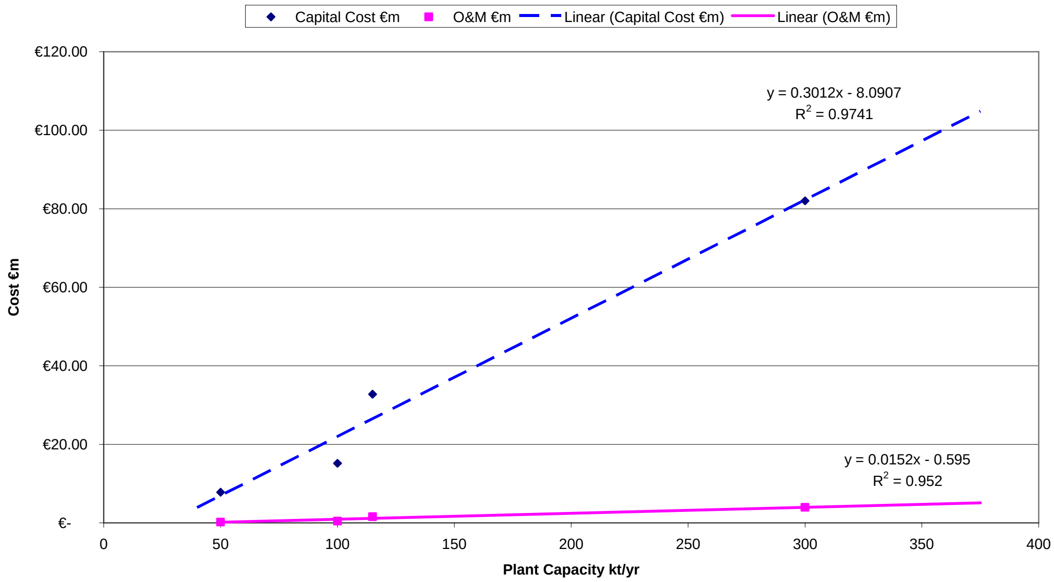
3.8.5 Resource Availability

24MWe is projected to be available at Glenavy fuelled by existing levels of chicken litter and related materials now being spread on land in North East Ireland.

3.8.6 Cost

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in this section and in the corresponding appendix.

Figure 3.8 - Chicken Litter Plant Cost Estimates



3.8.7 Conclusions

(1) It is projected that an energy recovery plant fuelled by dry agricultural wastes will be developed most probably in the Lough Neagh area which is the hub of the poultry industry in Northern Ireland and adjoining part of the Republic. The plant is rated at 24MWe with a levelised cost of electricity projected to be €0.07/kWhe, independent of gate fees, grants etc.

3.9 Wood Waste Combustion

3.9.1 Definition

Direct solid fuel combustion involves four stages (1) heating and drying of the fuel particle (2) Pyrolysis where the water and then volatile gases are driven out of the particle leaving a porous char residue which then experiences (3) flaming combustion where, in the presence of oxygen and with sufficient time, temperature and turbulence near complete consumption of the fuel can take place until (4) the residual core of the char particle reacts with adjoining gases in glowing combustion. Boiler and combustor designs have evolved to maximise the effectiveness of the combustion process and a variety of biomass materials are well suited to direct combustion. In general the larger the boiler the more efficient it can be.

Three major drawbacks to biomass combustion include relatively high moisture content, agglomeration and ash fouling due to alkais in the biomass and a reduction of thermodynamic efficiency at the scales appropriate to biomass fuelling so that their heat rates (amount of energy required per kWht) are higher than large fossil fuelled plants. Cofiring goes some way toward easing these problems as does fluidised bed combustion and gasification in a separate combuster.

Fluidised bed combusters can handle a variety of materials and while suffering from a number of drawbacks have proven capable of being scaled down to relatively small sizes (8-10MW) and have been applied to the combustion of chicken litter among other materials. In the smaller scales a variety of special grates and combustion systems have been evolved to counter the problems encountered in relation to the time/temperature/turbulence question where the physical size of the installation may militate against one or all of these criteria. The gas produced with air blown combustion may only have a heating value of 15% of that of national gas due to nitrogen dilution and it also has to be cleansed of its tar content. If the gas can be used hot as produced the conversion efficiency of the gasifier may reach 70-80% but if it has to be cooled this drops to 50-60%. At the smaller scales the gasification process is still considered to be somewhat developmental in commercial terms as are integrated gas turbine systems designed to produce electricity by utilising the gasification process.

3.9.2 Primary References

The primary sources of references are: Refs. (20, 4, 61).

3.9.3 Technological State of the Art

Many industrial processes (pulp production, brewing, sugar production etc. have large steady heat requirements that can be met by low pressure steam using their own residues as fuel.

In many cases energy conservation measures, improved drying, heat exchange, evaporation processes have led to reduced heat demand but an upward trend in electricity demand. Using a conventional boiler and steam engine or turbine (rankine cycle) is very scale dependent and at the smaller scales is only perhaps 10% efficient. Where the fuel is gasified for use in an internal combustion engine or gas turbine (Brayton cycle) the key challenge is to clear it to a standard where it is acceptable to these high performance systems.

This is relatively easy with biofuels but more problematic with products of thermal gasification on a larger scale particularly if they are to be fed to a gas turbine without loss of their sensible heat through cooling. The most common use of industrial scale gasifiers has been as precombustors e.g. Foster Wheeler CFB unit at Lahti (Finland) and Sydkraft IGCC unit at Varnamo using a CHP configuration where 18MW+ of biomass produced 6MWe+ 9MWth using a metal filter system to clean up the gas. The unit is now mothballed.

3.9.4 Basic Assumptions

- It is assumed for the purpose of this study that the most likely users of small scale CHP plant will be the sawmills (using wood residue) which require heat for timber drying and are in a position to generate electricity for their own needs and feed into the network.

These processes can be variable seasonally and on a more short term basis.

3.9.5 Resource Availability

Table 3.10

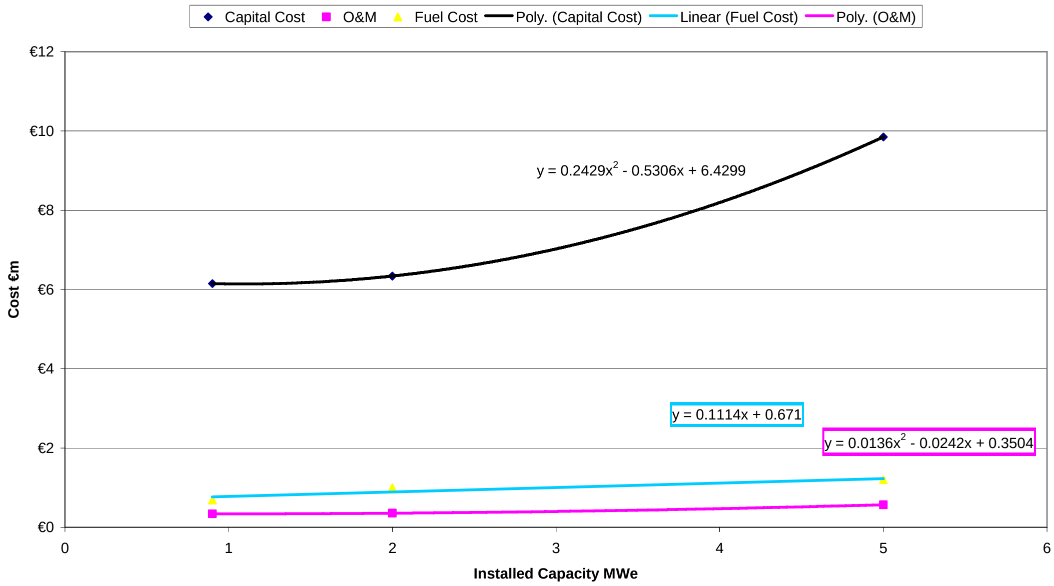
Wood Waste Combustion (CHP) Resource

Name	Installed Capacity MW	X	Y	Fuel	110kV Node	Levelised Cost € per kWhr
Munster Joinery CHP	5	115590	104240	Wood Biomass	Glenlara	€0.08
Balcas Joinery CHP	3	223440	344220	Wood Biomass	ENNISKILLEN MAIN	€0.10
Murray Joinery CHP	2	178560	252660	Wood Biomass	Athlone	€0.14
Graingers Sawmills CHP	2.7	136000	54500	Wood Biomass	Bandon	€0.11

3.9.6 Cost

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in Figure 3.8 and in the corresponding appendix.

Figure 3.9 - Small Sawmill CHP Plant Costs



3.9.7 Conclusions

(1) CHP installations at saw mills are primarily installed to provide low-medium level heat for timber drying.

(2) The heat demand varies seasonally and fuelling is by sawmill residues which were formerly regarded totally as waste materials although they now have potential value as sources of chips and pellets. This fuel is not “free” as about 50% of the bought in saw wood ends up in this category.

(3) A total projected capacity of 12.7MWe is identified with a levelised cost range of €0.07 – 0.09/kWhe reflecting fuel cost and variable capacity factor for the electrical installation. They form part of the thermal waste resource of Portfolios 1-6.

4 Ocean Energy: Wave

4.1 Definition

Wave energy is really a form of stored wind energy that has been transferred through friction and turbulence across the air-sea interface over a period of time and distance. Wind is itself derived from the effect of differential solar heating of the earths surface, changes in atmospheric pressure and is influenced by the rotation of the earth on its axis and the topography over which it passes. Waves are characterised by their length, height and period but because of their random nature most measurements and analyses involve the use of statistical parameters. The size of waves generated by a given wind depends on its speed, the duration of its influence and the distance over which the wind can bring its influence to bear on the wave surface.

Strong winds or storms produce irregular wind or storm waves in the local area in which they occur e.g. the Carribean for example but as they radiate out across the ocean these waves transform into families of regular smooth waves (or swell) that can travel for thousands of kilometres. When they encounter further local winds or storms these produce more local wind waves that superimpose themselves on the underlying swell leading to complex wave patterns. (The result has been likened to throwing fifty sheets of corrugated roofing into the air and allowing them to fall randomly in any direction upon each other).

It is thus a fact that the highly irregular and random sea can be broken down into a large number of simple wave farms for analytical purposes, the energy content being propositional to the square of the wave height multiplied by the period, measured in seconds that the wave would take to pass a stationary observer.

Hundreds of different devices have been conceptualised as a means of extracting energy from waves but it is outside the scope of this report to discuss more than a few. The interested reader may refer to Ref. (70) for further reading.

4.2 Primary References

The primary sources of references are: Refs. (39, 47, 68, 71).

4.3 State-of-the-Art of Technology

Early converter concepts usually involved rigid attachment to the sea bed or a coastal structure and some still do but waves arriving in shallow water have lost much of their energy and the trend has been toward development of floating converters designed to exploit the most frequently occurring characteristics of the wave field in which they will be located.

A key issue to be resolved in each case relates to the production of high quality electricity complying with precise standards from such an irregular source of energy as the waves. This has been resolved in a number of ways by developers of different converter systems involving bidirectional (rectifying) air turbines, hydraulic motors, compressed air storage, water storage etc.

It is usual to test converter concepts using scale models in special test basins where different types of wave can be generated, such as those (in Ireland) at University College Cork or at Queens University. The model performance can be analysed and the scale increased until further testing must be carried out at very large test basins or at sea. A 1 : 4 scale test facility is maintained by the Irish Marine Institute at Galway Bay. A full scale test site with network connection is operational at the European Marine Evaluation Centre in Orkney and a site evaluation process is underway to develop one in Ireland. Such centres provide a developmental and certification service to converter developers under open ocean conditions. A key developer requirement includes the production of a credible scatter table which relates the machines electrical output to the way in which it responds to the periodicity and significant wave height that it is experiencing. Demonstration of safe and successful operation as designed under prolonged operation at sea is also essential.

It was reported Ref. (68) in 2006 that 9 devices were being tested at field (or near full scale) at sea and that 26 developers were testing point scale models. A small sample of converters which warrant mention are Pelamis, Wave Dragon, Archimedan Wave Swing, Powerbuoy, OES buoy, Wavebob.

Pelamis (750kWe) was used as the reference machine in the Irish Wave Atlas while Wave Dragon (7MW) has been used in this study because of its potential economy of scale from a utility perspective. The atlas software requires the provision of a scatter table for each machine being considered and not all developers are in a position to provide this. Two machines currently undergoing test at the Galway Bay site are Wave Bob (Hydraulic) and OES Buoy (oscillating water column).

4.4 Basic Assumptions

- It is assumed that the methodology of the Irish Wave Atlas 2005, based on 3.5 years of hourly wave predictions, modified locally by buoy measurements at six locations, provides a representative mean wave climate for the waters surrounding Ireland. As further data becomes available the method can be updated.
- It is assumed that the power tables supplied by Wave Dragon Wales Ltd. and Ocean Power Delivery accurately represent the performance of these converters and that the spacing specified by the designers can be achieved.

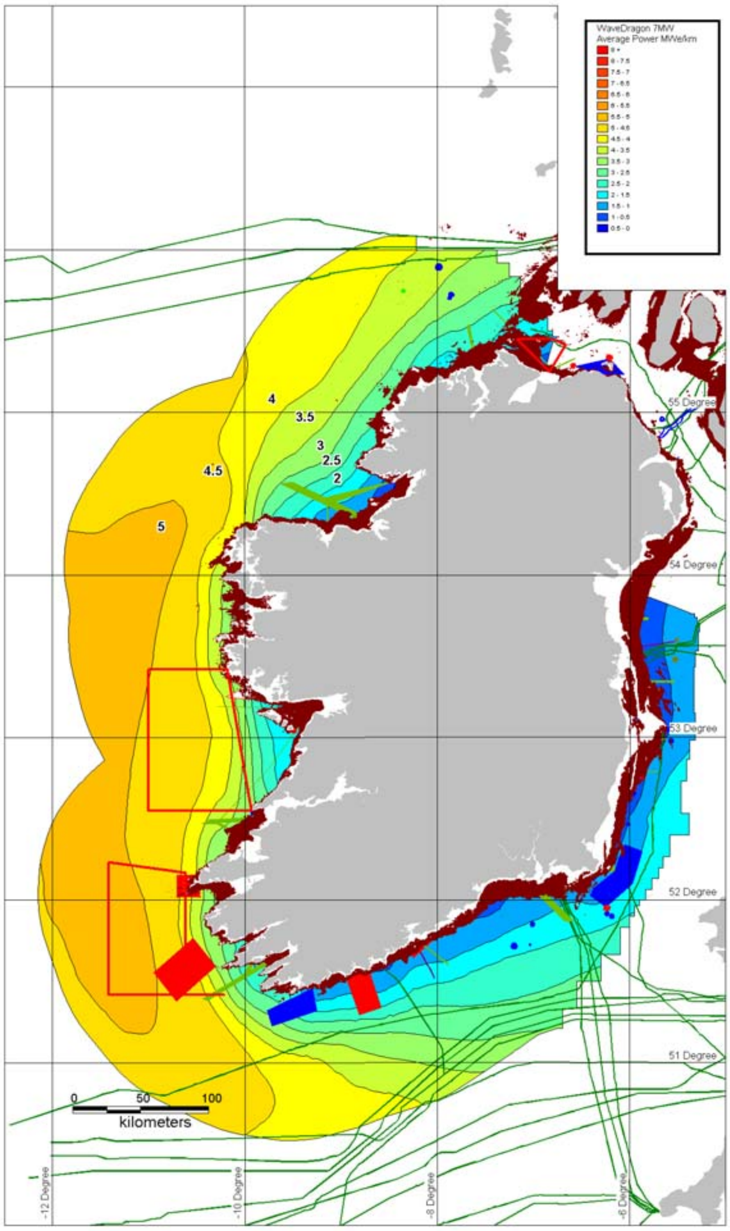
- The analysis provided utilises the Wave Dragon assuming that the 7MW unit is available by 2020. (A fall back would be to use the currently available smaller Pelamis 750kW machine which would require that the machine cordons feeding the respective 110kV nodes were each about 2.5 times longer than those shown for Wave Dragon).
- It is assumed that the necessary proving and engagement process with other marine stakeholders will have been successfully accomplished within the Foreshore Licencing procedures so that the projected wave energy developments can proceed successfully to meet the appropriate dates.
- It is assumed that the necessary market and other conditions will be in place to facilitate such development.
- It is assumed that the primary wave energy resource for the Single Electricity Market will be located off the Republic of Ireland.
- It is assumed that an AC transmission link to shore will be used based on the following:
    - The offshore distances to the wave farms range in general between 9.9 and 27km with one exceptional case having a cable length of 84km to reach the coast in a diagonal direction. The average offshore cable length is 24.5km.
    - The average onshore distance however is 63.3km thus the onshore distances outweigh the offshore distances by a factor of 2.5 due to the distribution of existing 110kV nodes.
    - The question of power transmission from wave power plants is discussed in Ref. (71). Broadly speaking HVDC comes into its own at voltages above 110kV and/or distances greater than about 50km. It also requires a significant footprint on land at each end for the converter/rectifying stations.
    - The depths at the wave farm locations vary between 120-200m, averaging 150m. These depths of water, subject to Atlantic wave conditions, do not readily lend themselves to the construction of rigid platforms of the scale required to accommodate HVDC transmission stations even if the necessary stations could readily be accommodated onshore. It is considered that the onshore link to the nearest 110kV station will always be more cost effective as an overhead line than an underground cable. For the purpose of this study attention has focussed on a floating 110kV station using marinised equipment and gas insulated switchgear with the power being transmitted onwards to the shore using conventional compliantly attached armoured cable lying on the sea bed. It is believed that the distances involved, apart possibly from 'West D' wave farm, make this form of AC transmission more cost effective than HVDC. It will of course be a matter for wave farm developers to select the technology that they consider to be most appropriate to their own particular converter systems. In this report the emphasis is on feasibility.

4.5 Available Resource

4.5.1 Introduction

Preliminary assessments of the available resource have been described in Refs. (17) and this study is based on an application of Ref. (39), an extract of which is shown in Figure 4.1 below.

Figure 4.1 Mean Annual Accessible Power Resource



ESB International
Environmental Services 2005

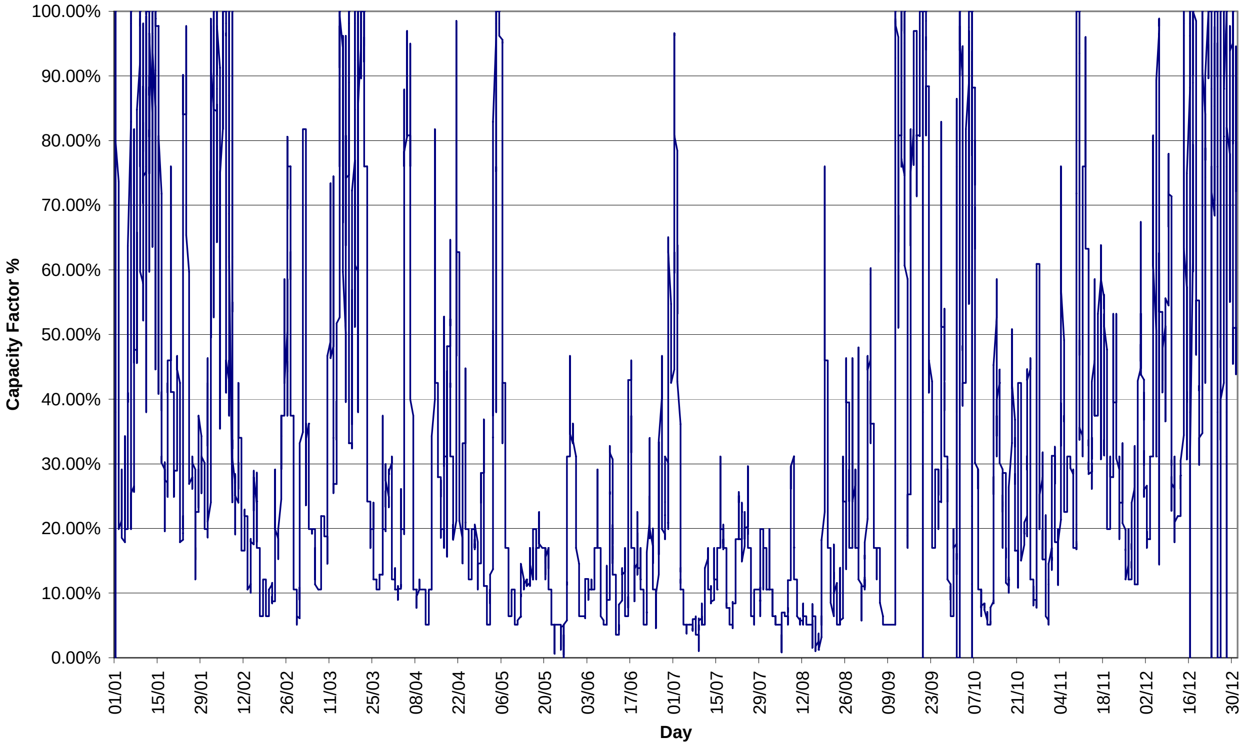
Fig No. 13 Mean Annual Accessible Power Resource (WaveDragon) MWe/km

4.5.2 Wave Capacity Curve 2004

Worksream 1 was asked to provide Workstream 2b with a time series power output curve for the period 1st January to 31st December 2004. This was achieved by using the wave resource time series data used in Ref. (17) given in terms of significant wave height and zero crossing period and applying it to the power table for the Wave Dragon (7MW). This enabled production of electrical power offtake time series data on an hourly basis for each individual wave farm. Figure 4.2 shows the time series for the Northwest Wave Farm group.

Figure 4.2

Output Time Series (2004) for Northwest Wave Farm



4.6 Costs

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in this section and in the corresponding appendix.

Table 4.1

Key Attributes used in the Determination of Indicative Levelised Cost for each km square in the GIS database Wave

Attribute	Relevance to Indicative Levelised Cost
Installed Capacity	Number, rating and spacing of wave power converters to be installed.
Annual Energy Yield	Calculated from the wave power resource at location, giving the mean long term potential energy yield from the installation (MWhe).
Location of Offshore 110kV transformers station	The two sets of coordinates provide indicative lengths for submarine cable and overhead line to the nearest network connection point which in turn have a cost implication for the site.
Location of nearest available terrestrial 110kV station	

Table 4.2

Costs Associated with Development, Operations, and Maintenance of Wave Farm Projects

Item	Description	Unit	Rate €k	Subtotal €k
1. 1.1 1.2	Wave Farm Converters Offshore Wave Converter Installation (less discount) Internal farm compliant MV cables	 2 No./km x Km	 2857/MWe 155/km	NWA : 374 (€M) MWB : 340 “ NWC : 374 “ WA : 272 “ WB : 272 “ WC : 272 “ WD : 238 “ SWA : 340 “ SWB : 306 “ SWC : 340 “ SWD : 272 “
2. 2.1 2.2 2.3	Floating offshore 110kV Trafo Station Provide, fit out, more specific hull type 80MVA/20MVA switchgear	 1 No. 1 No. 1 No.	 1,000 241 600	NWA : 5482 MWB : 6082 NWC : 6142 WA : 5162

Item	Description	Unit	Rate €k	Subtotal €k
2.4 2.5	31.5MVA 110kV Marinised Trafo 110kV GIS Switchgear Control Protection S./gear Circuits	1 No. 1 No.	200 30	WB : 5162 WC : 5162 WD : 5102 SWA : 6082 SWB : 5222 SWC : 6082 SWD : 5162
3. 3.1 3.2 3.3 3.4 3.5 3.6 3.7	Seabed Cable Trafo. Stn. To Shore 110kV Armoured Cable (wriggle factor 1.15) Pre & Post Installation Survey Lay Barge Mobilisation Cable Installation Cable Jointing Cable Spares/Accessories Cable Foreshore Licence	Length/Km 1 No. 1 No. x Km x No Sum Sum	800 700 3,000 300 (75) 800 300	NWA : 27,421 MWB : 19,699 NWC : 28,345 WA : 36,025 WB : 36,497 WC : 39,228 WD : 111,219 SWA : 17,554 SWB : 21,272 SWC : 23,747 SWD : 34,978
4. 4.1 4.2	Overhead Line End Mast terminations 110kV O.H. line (wriggle factor 1.15)	2 No length/Km	140 180	NWA : 12,384 MWB : 10,872 NWC : 17,741
5. 5.1	Receiving 110kV Station Station Upgrade (incl. metering, civils)	Sum	3,000	WA : 20,605 WB : 24,214 WC : 19,968 WD : 11,450 SWA : 15,349 SWB : 14,955 SWC : 18,951 SWD : 16,440
6. 6.1	Operation & Maintenance % of Total Capital Cost/yr	%	3	NWA : 12,984 NWB : 11,641 NWC : 13,192 WA : 10,221 WB : 10,343 WC : 10,298

Item	Description	Unit	Rate €k	Subtotal €k
				WD : 11,135 SWA : 11,693 SWB : 10,690 SWC : 11,987 SWD : 10,073

Table 4.3

Items included under each Cost Heading (Wave)

	Cost Heading	Items
1.	Wave Farm Converters	Converter compliantly moored on station incorporating low head hydro turbines, unit transformers, protection and control systems for MV operation in compliance with Distribution code with compliant cable link via adjoining converters to floating 110kV station, incl. associated project management, testing, commissioning, insurances, permitting and safety compliances.
2.	Floating 110kV Station	Provision, survey, modification and fit out of suitable surplus hull to carry listed equipment for operation in unmanned mode while moored at wave farm site. (Including testing and commissioning).
3.	Seabed Cable to Shore	Provision and laying of 110kV armoured cable between floating 110kV station and end mast of overhead line on shore in compliance with specification and regulatory requirements, including added cable protection in shallow sub-littoral zone. (Including testing and commissioning).
4.	Overhead Line	110kV overhead line, rated for appropriate load, between end masts at shoreline and receiving inland 110kV station in compliance with TSO/DSO specification and regulatory requirements (including testing and commissioning).
5.	Receiving 110kV station upgrade	Provision of additional compound space, bays, busbars, founds, structures, ducts, circuits and equipment as required to meet TSO/DSO specifications and requirements including testing and commissioning.
6.	Annual O&M	Land Lease/Wayleave rentals, infrastructure maintenance, electrical imports, TUOS operations, grid maintenance, insurances, rates and levies, marine operations, spares, reserves and contingencies.

Table 4.4

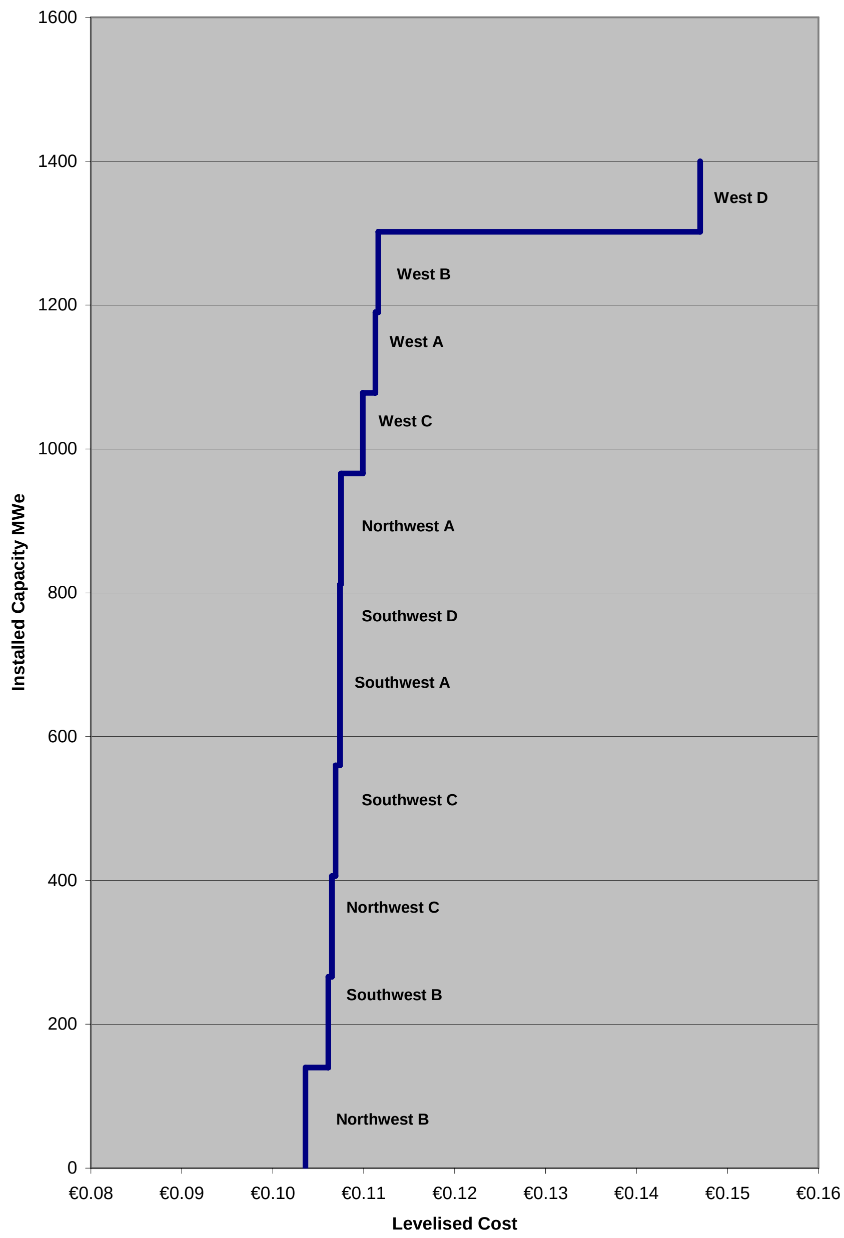
Projected Links between Wave Farms and 110kV Stations

Name	Installed Capacity MWe	110kV Station	Levelised Cost €/kWhr
North West A	154	Tawnaghmore	€0.108
North West B	140	Bellacorrick	€0.104
North West C	154	Castlebar	€0.107
West A	112	Dalton	€0.111
West B	112	Cloon	€0.112
West C	112	Galway	€0.110
West D	98	Ennis	€0.147
South West A	140	Tralee	€0.107
South West B	126	Oughtragh	€0.106
South West C	140	Knockearagh	€0.107
South West D	112	Ballylicky	€0.107

Figure 4.3

Resultant Wave Farms (1400MW) and Associated 110kV nodes

Figure 4.4 Portfolio 6: Wave Power Resource Cost Curve



4.7 Conclusions

(1) The methodology developed during production of Ref. (17) has been used to estimate the accessible wave energy resource on the Irish West Coast, utilising the floating Wave Dragon as the reference converter in this instance.

(2) Prime sites have been identified off the Mayo, Galway and Kerry coasts and the estimated spread of converters necessary to meet the Portfolio 6 plant requirements for 2020 of 1400MWe were identified.

(3) The distribution of converters is shown on the accompanying diagram (Figure A8-15). It is arranged so that the power loading on any of the target 110kV stations does not exceed circa 150MW as summarised in Table A8.4.4.

(4) The projected levelised cost ranges between €0.104 and €0.112/KWhe with the exception of the West D site which lies relatively further offshore from the 110kV node (Ennis) to which it is linked than the other sites.

(5) It is appropriate to issue the above data to the consultants carrying out the other workstreams on this project.

5 Ocean Energy: Tidal

5.1 Introduction

A preliminary assessment between the Marine Current Tidal (MCT) converter as projected for test installation at Strangford Lough and the TidEl converter, which is a midwater buoyant design potentially capable of installation in a greater range of locations and with a possibly lower capital cost led to the conclusion that initial attention should at this point focus on the MCT system. It is, of course, recognised that a number of competing designs are currently under development and that some of these may reach the commercial stage before 2020.

The gravitational pull of the Sun and Moon on the waters of the oceans causes a variable but predictable build up and depression of water level. This is recognised in daily variations in tide level which are accompanied by flows along the Irish coast to and from the Atlantic Ocean. Other currents may arise due to regional temperature or pressure gradients and wind effects. The combined currents are accelerated where they funnel through narrow straits e.g. the North Channel between Scotland and Northern Ireland or round prominent coastal features e.g. Carnsore Point.

Various types of turbines have been developed to recover energy from these tidal streams which, although they may not match the wind for speed, are predictable and contain comparable energy due to the density of water compared to that of air. This is the resource that has been targeted in this section of the report.

5.2 Primary References

The primary sources of information used, amplified by reference to Admiralty Charts, Coast Pilot and tide tables, were respectively References 10, 16, 28, 67.

5.3 Technological State of the Art

Modern tidal stream of current converters are at a relatively early stage of development. Although work has been under way for upwards of 10-15 years it is only in recent years that designs have reached the stage that full scale ‘first generation’ machines have become available following successful test operation of smaller scale developmental units over the past few years.

Approximately 15 concepts are under development in laboratories and test sites in various countries including UK, Norway, Italy, Canada and Ireland. Ref. (68). The Open Hydro converter developed by a Dublin based company is currently under test at the European Marine Energy Test Centre in Orkney.

For the purposes of this study attention has focussed on the first generation 1.2MW Seagen converter developed by Marine Current Turbines of UK.

A prototype of the Seagen converter is being installed in Strangford Lough this year, where its environmental effects will be closely monitored. This type had been utilised as the bench mark machine in the studies referenced above. It consists of a pair of rotor driven generators mounted on the ends of wings extending from the sides of a steel tower piled or socketed into the seabed. The generators may be raised up along the tower to the sea surface for access or replacement. The blade pitch can be changed to match the direction and strength of the current which of course varies throughout the day. Other first generation converters are bed mounted utilising ballast or anchor piles and in some cases the impellor is shrouded to augment current velocity by venture action. Spacing in the upstream-downstream direction can be rather critical to avoid losses due to turbulence.

Second generation machines are at a still earlier stage of development. These may be visualised as rotors mounted as buoyant torpedo shaped nacelles floating at about mid depth in the tidal stream but moored to seabed fixtures by an arrangement of cables that assures stability in the current flow. This eliminates the expense and depth limitations of the tower or structural framework required in the first generation machines. They can also be located in the stronger currents further away from the coast, utilise larger rotors, can conceptually change direction to accept reversal of current flow and come to the surface for servicing/removal. Other concepts utilise attachment to a moored surface buoy as well as the sea bed.

While attractive, these concepts face challenges in the assurance of stability under the turbulent eddies and cross currents that they are likely to encounter at various stages in the tidal cycle. One typical ‘second generation’ device is the tidEL converter (UK) which appeared promising but where development is understood to have slowed significantly in recent times.

5.4 Basic Assumptions

- It is assumed that the tidal resource is as estimated in the reports Refs. (10, 16) and that a representative annual tidal time history is as per the curve supplied.
- It is assumed that the MCT prototype tidal converter will be installed as planned in Strangford Lough during 2007 and will function successfully without significant environmental impact.
- It is assumed that this will open the way to the deployment by developers of “first generation” machines of MCT or similar type at inshore sites during the period 2010 – 2015.
- It is assumed that the development of tethered floating ‘second generation’ machines accelerates and that the production versions of these converters are available for installation from 2015 onwards to make up the requisite installed capacity for 2020.

- It is assumed that the necessary proving and engagement process with other marine stakeholders will have been successfully accomplished within the Foreshore Licencing procedures so that the projected tidal energy developments can proceed successfully to meet the appropriate dates.
- It is assumed that the necessary market and other conditions will be in place to facilitate such development.
- It is assumed that the primary tidal resource for the Single Electricity Market will be located off Northern Ireland.

5.5 Resource Availability

5.1 Introduction

Estimates based on the above references have been made and are tabulated in Appendix 9. These show:

(1) A mean annual **theoretical** resource (whole island) for the waters between the nearshore depth contour of 10m and the 12 nautical mile territorial limit of 230TWh/year.

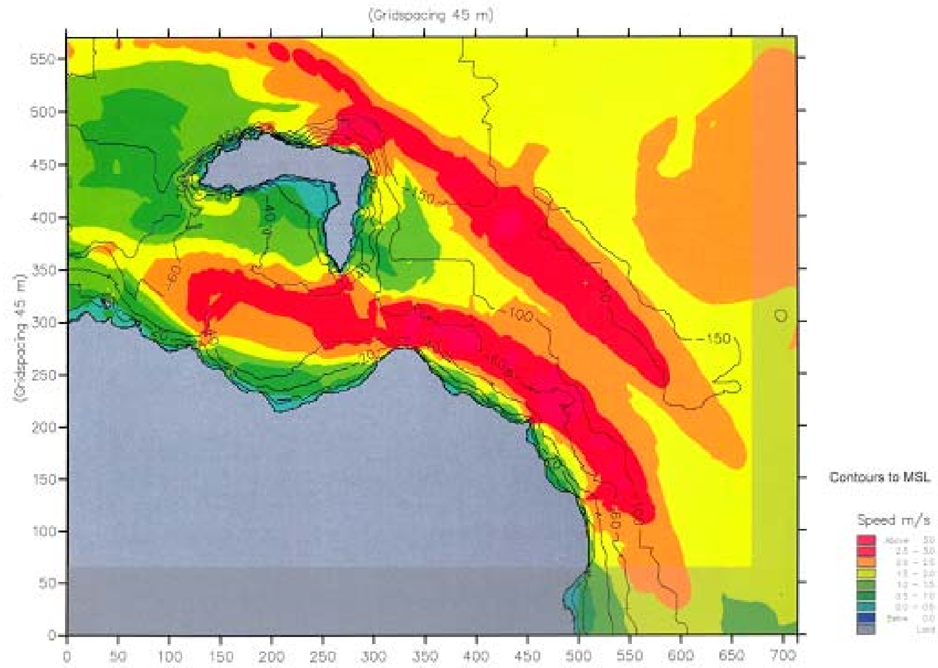
(2) When confined to areas having peak current velocities exceeding 1.75m/sec. and utilising a conversion efficiency of 39%, this falls to a mean **technical** resource level of 10.46Twhe/yr. spread over a number of locations.

(3) Using the first generation MCT reference turbine, which has an operating depth range of 20m – 40m, at the eleven most significant sites, the mean **practicable** resource falls further to an estimated 2.63Twhe/yr.

(4) Finally the mean annual **accessible** resource using first generation tidal converter is estimated at 914Gwhe/yr. of which 373Gwhe/yr are adjacent to the coast of the Republic and 541Gwhe/yr occur along the coast of Northern Ireland at locations listed in Appendix 9.

Figure 5.1 – Peak Spring Tidal Speeds North & North East coasts

(Based on Ref. 10)



5.2 Power Output Curves (2004)

Workstream 1 was asked to provide Workstream 2b with an output power curve for Tidal energy. This was achieved by taking a time series that developed by Ref (16) and altering it to reflect the expected output from both first generation and second generation tidal converters.

Figure 5.2 illustrates a typical annual output time series from the NE Coast 39MWe facility X2.

Figure 5.2 – Output Time Series (2004) for the NE Coast 39MWe Facility X2

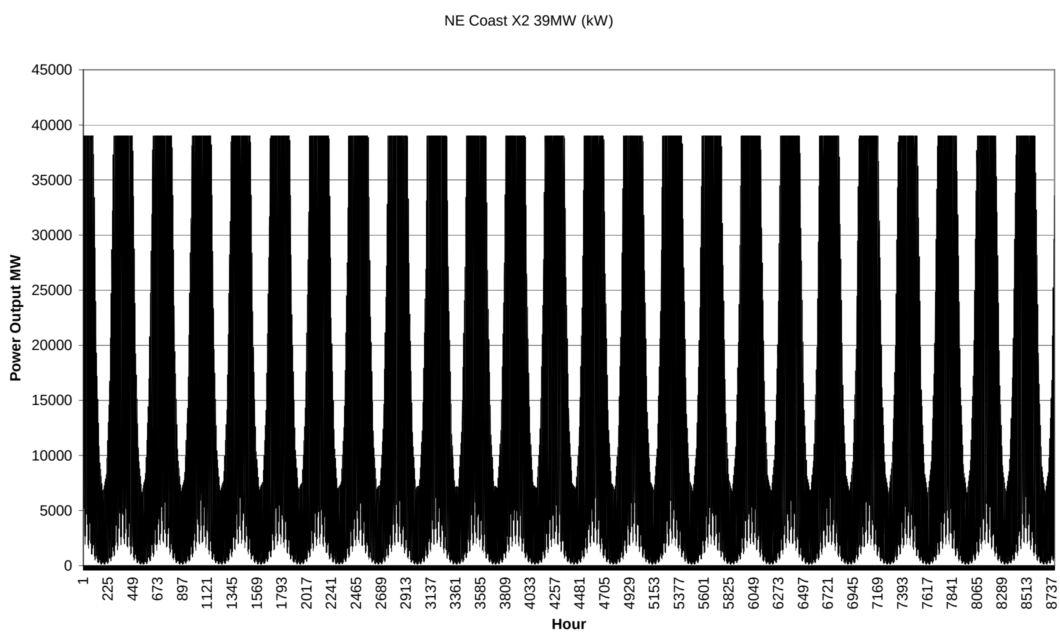


Figure 5.3 – Spatial Distribution of Tidal Stream Plant for Portfolios 1 to 4

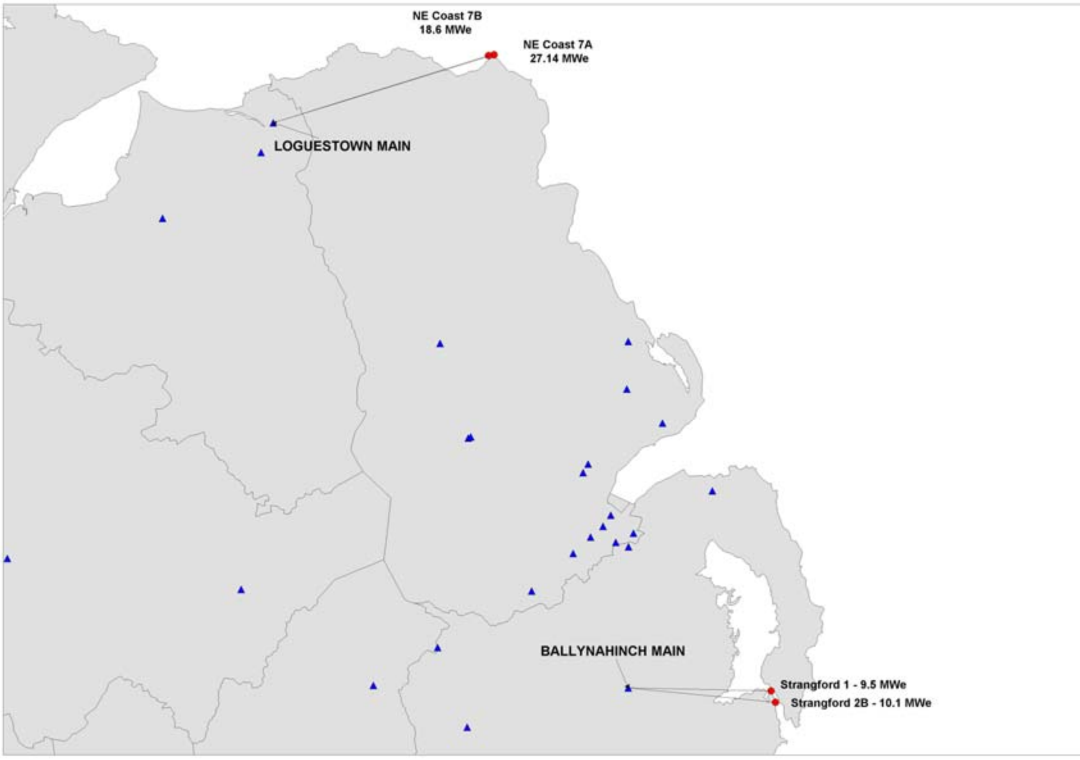
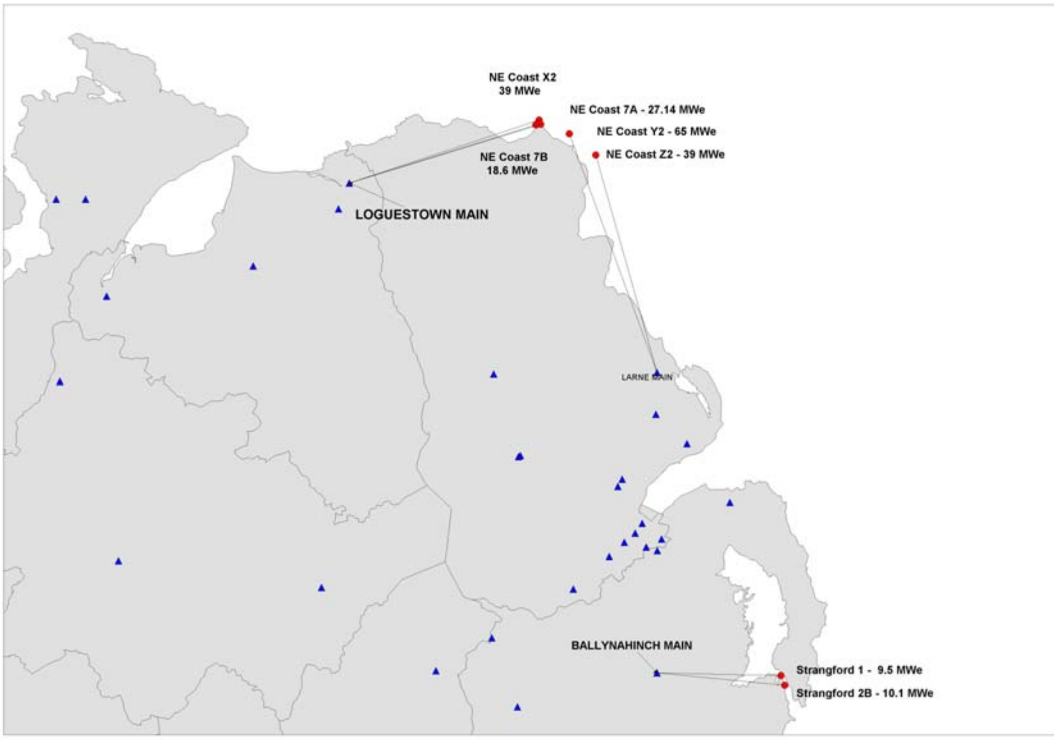


Figure 5.4 - Spatial Distribution of Tidal Stream Plant for Portfolios 5 & 6



5.6 Costs

Because of the limited experience of full scale projects to date, cost projections are inevitably subject to a greater degree of uncertainty than would apply for example, in the more established wind power industry. In this study a two stage costing process was utilised. First, in order to demonstrate the relative difference between the cost of the resource in Northern Ireland and that in the Republic the levelised costs for the different sites developed in the RPS studies (Refs. 10, 16) were ranked and plotted as in Fig. A9-1.

Table 5.1

Key Attributes used in Determination of Indicative Levelised Cost

For each km square in GIS Database – Tidal Power

Attribute	**Relevance to Indicative Levelised Cost**
Installed Capacity	Number, rating and block location of tidal power converters to be installed.
Annual Energy Yield	Calculated from the tidal power resource at location giving the mean long term potential energy yield from the installation (Mwhe).
Location of Offshore block reference point	These two sets of coordinates provide indicative lengths for submarine cable and overhead line to the nearest network connection point which in turn have a cost implication for the site.
Location of nearest available terrestrial 110kV station	

Table 5.2

Items included under each cost heading wave – Tidal Power

	Cost Heading	Items
1.	Tidal Power Turbines	First Generation Converters: Inshore Seabed mounted tidal stream converters incorporating rotors, generators, transformers, protection and control systems for MV operation in compliance with Distribution Code with seabed cable links within farm to reference point incl. associated project management testing commissioning, insurances, permitting and safety compliances. Second Generation Converters: As above but with submerged floating converters moored to seabed on station further offshore.
2.	Reference Point	Geographic coordinates
3.	Seabed Cable to Shore	Provision and laying of armoured cable between farm reference point and shore in compliance with specification regulatory requirements, including added cable protection in shallow sub littoral zone (including testing and commissioning)
4.	Overhead Line	Overhead line rated for appropriate load between end masts at shoreline and receiving inland 110kV station in compliance with TSO/DSO specification and regulatory requirements (including testing and commissioning).
5.	Receiving 110kV Station Upgrade	Provision of additional compound space, bays, busbars, structures circuits and equipment as required to meet TSO/DSO specifications and requirements including testing and commissioning.
6.	Annual O&M	Land lease/wayleave rentals, infrastructure maintenance, electrical imports, TUOS operations, grid maintenance, insurances rates and levies, marine operations, spares reserve funds and contingencies.

Table 5.3

Projected Cost Base for Development, Operations and Maintenance of Tidal Current Projects

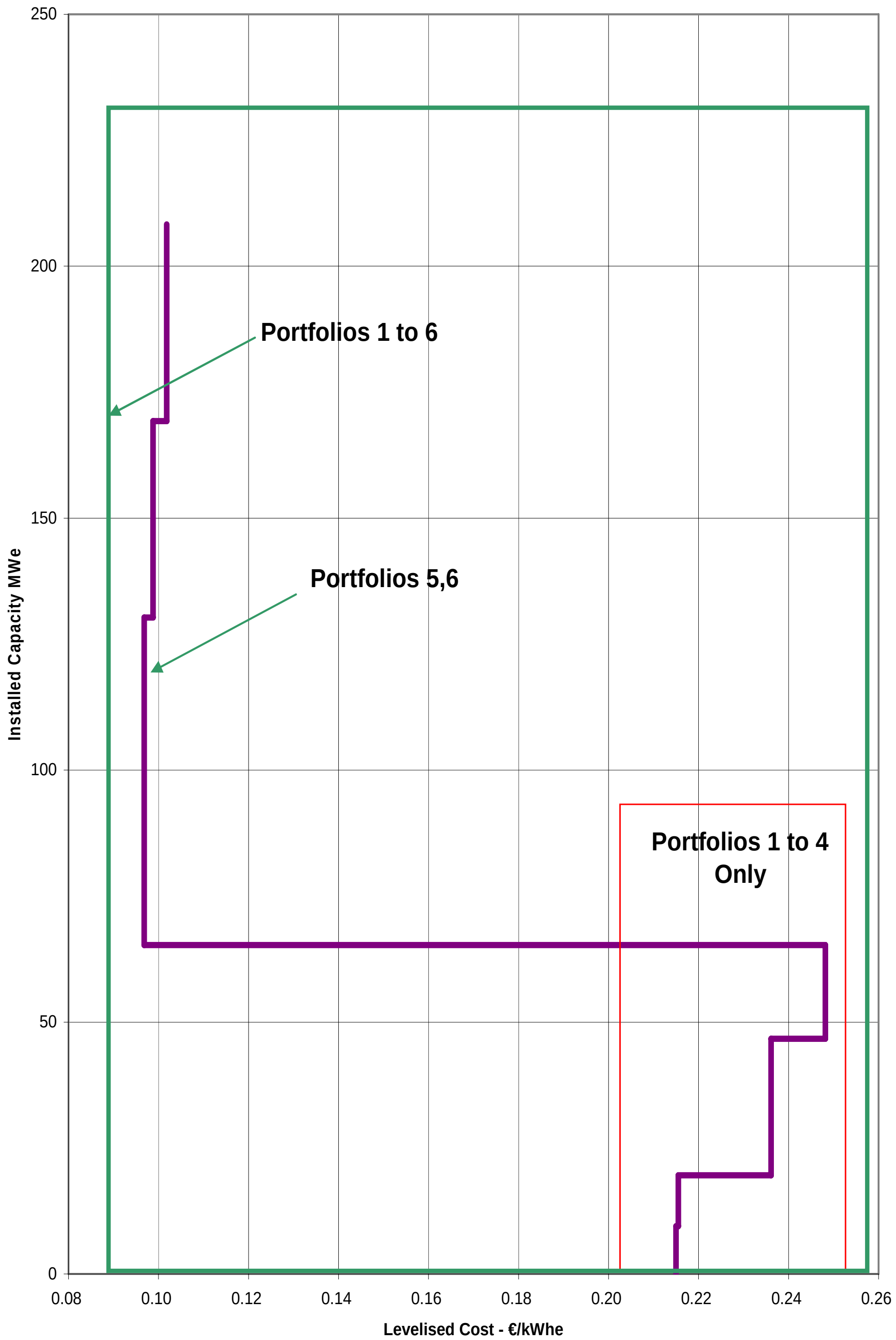
Item	Description	Unit	Rate €k	Subtotal €k
1. 1.1 1.2	Tidal Current Converters Provision and installation of converters Internal Farm seabed cabling	 Farm Rating/MWe Length km	 2490/MWe 150/km	1 : 40,481 2B : 43,038 7A : 115,649 7B: 79,258 X2 : 97,110 Z2 : 97,110 Y2 : 161,850
2. 2.1 2.2	Coastal Trafo Station Apportioned share of new 33kV Trafo. Stn. (€1125k) Metering (MV)	 Sum No	 Varies 25/farm	1 : 570 2B : 605 7A : 960 7B: 659 X2 : 1,381 Z2 : 1,125 Y2 : 1,875
3. 3.1 3.2 3.3 3.4 3.5	Seabed Cabling (Ref. Point to Shore) Provide, lay, commission armoured cable (length wriggle factor 1.3) Surveys Mobilise lay barge Cable Spares/accessories Foreshore licencing	 Length/km Sum €k 1 No. 1 Set €k	 100/km 200 400 125 100	1 : 3,850 2B : 2,775 7A : 10,790 7B: 9,280 X2 : 2,850 Z2 : 4,200 Y2 : 2,950
4. 4.1 4.2	Overhead Line (33kV) End mast terminations (apportioned) 33kV O.H. land line (factor 1.15)	 2 No. Length Km	 40 95/km	1 : 1,199 2B : 1,268 7A : 2,537

Table 5.4

Tidal Sites Ranked to meet Portfolio Requirements

Portfolio	Site	Capacity (MWe)	110kV	Balance (MWe)	Levelised Cost €	Generation
1 – 4 (70MWe Req.)	2B 1 7A 7B	10.1 9.5 27.14 18.6 (65.34)	Ballynahinch Ballynahinch Loguestown Loguestown	Shortfall 4.7	0.22 0.22 0.24 0.25	1st
5 - 6 (200MWe Req.)	Z2 X2 Y2	39 39 65 (143)	Larne Loguestown Larne	Surplus 8.34	0.10 0.10 0.10	2nd
		(208.34)				

Figure 5.5 - Portfolios 1 - 6:
Tidal Power Resource Cost Curve



5.7 Conclusions

(1) Evaluation of the tidal stream resource, within the 12NM limit, round the island of Ireland has been based on the referenced reports and contact with converter developers, both of first (20m < depth < 40m) and second generation (depths > 40m) systems.

(2) The **theoretical** tidal stream resource is estimated at 230TWh/yr in hydrodynamic terms.

(3) Utilising first generation bed mounted converters of the MCT type at locations with peak current velocities exceeding 1.75m/sec. and a conversion efficiency of 39% yields a **technical** energy resource of 10.46TWhe/yr.

(4) Focussing on 11 key sites north and south the mean annual **practicable** resource falls to 2.63TWhe/yr (elec.)

(5) Elimination of legally constrained and minor areas leads to a residual **accessible** energy resource of 541GWhe/yr for Northern Ireland and 373GWhe/yr for the Republic, totalling 914GWhe/yr. (First Generation).

(6) A much larger second generation resource of 3.1TWhe/yr is estimated to be available primarily off Northern Ireland. It remains to be seen when this technology becomes commercially available and whether the implied capacity factors can be achieved or not.

(7) Capacity factors implied by the yields of Table A9-2 range between 0.19 and 0.57 and have been questioned on the basis that they may depend on particularly favourable ratios between neap and spring tide current velocity.

(8) It has been shown that by effectively derating the electrical capacity of tidal turbines to a value below the implied mechanical capacity it is possible to increase capacity factor in the 50m diam. installation of Table A9-2 to 0.42.

(9) However bearing in mind the relatively small scale of the projected tidal installations called for in the Portfolio this is not an unduly significant issue at this stage. Most commentators agree that the real commercial success or otherwise of tidal energy will depend on second generation machines.

(10) An initial costing of first generation technology at the respective sites allows a preliminary ranking to be made. This shows that the Northern Ireland sites are uniformly more cost effective than these in the Republic. (Fig. A9.1)

(11) Bearing in mind that this is a new technology and the competitive advantages available to other technologies it is considered that installation might credibly range between 2MWe (2010), 12MWe (2012) 20MWe (2015) and 70MWe (2020). This would lead to a shortfall of 130MWe for Portfolios 5 & 6 in 2020 although satisfying the needs of Portfolios 1 to 4.

(12) Assuming an active programme of installation of first **and** second generation converters proves possible, the respective portfolio requirements can however be met by the sites listed in Table A9.3.

6 Wood Co-combustion

6.1 Definition

Cocombustion involves the partial fuelling of the steam generation system of a power station by biomass. In most circumstances the pulverised biomass is fed directly into the boiler that in others it may be fed to either a gasifier, with the product gas being used to augment the main boiler fuel, or to an auxiliary boiler whose heat is used to supplement that of the main boiler. These variations may arise because the biomass contains some elements that could cause problems if fed directly into the main station boiler. The woody material may be a forest product or derived from short rotation coppice.

The primary reason for cofiring relates to reduction of the CO^2 footprint of the plant but other factors may arise such as proximity to a source of supply.

Cofiring with biomass can influence the operation and reliability of the power plant and factors which must be considered individually in each case include:

- Steam Generator (fuel storage and handling system, slagging/fouling or corrosion or boiler subsystems)
- Flue Gas Cleaning (deposits on precipitators, deactivation of catalyst)
- Residues (quality of ash and gypsum)
- Emissions (NOx, CO_2).

In the context of this report Portfolios 1-4 had included the premise that up to 30% cocombustion could take place at the three midland peat fired plants which have fluidised bed boilers. Portfolios 5, 6 required additional biomass cofiring and this is projected to be achieved at Tawnaghmore, Kilroot and Moneypoint.

6.2 Primary References

The primary sources of references are: Refs. (14, 15, 20, 45, 61, 64, 65).

6.3 Technological State of the Art

For a long term commitment to wood biomass cocombustion at the existing peat fired stations the following systems might typically be required assuming delivery of prechipped or pelletised wood via back typing trucks:

- Dual chip samples/weighbridge
- Wood chip storage building (enclosed steel portal structure)
- Mobile plant + Misting system in store
- Push floor reclaimer feeder
- Wood chip silos/surge bunkers (steel)

- Conveyor to mills
- Isotope mass meter for wood chip quantification.

If it was intended to take delivery of logs instead of chip the following additional assets would be required:

- Log storage yard
- Dual log samplers
- Mobile log grab
- Plant garage
- Fixed debarker/wood chipper
- Accoustic enclosure for chipper.

For importation of prechipped biomass by sea at Moneypoint and Kilroot, plant required would include:

- Modifications to existing marine terminal
- Chip conveying system to store
- Dual chip samplers
- Wood chip storage building (with misting system)
- Mobile plant
- Push floor reclaimer feeder
- Wood chip silos/surge bunkers (steel)
- Conveyor to mills
- Possible additional milling capacity
- Isotope mass meter for wood chip quantification
- Possible modifications to ashing system.

Tawnaghmore is envisaged to be equipped with wood handling facilities from the start.

A key factor influencing cost is the amount of storage required which is a function of numerous variables such as planned operating regime, source, method and frequency of deliveries etc.

Therefore Wood Cocombustion Plant involves fuel handling, storage, reclamation, size, reduction, weighing, feed and, where appropriate, separate ash handling and disposal.

6.4 Basic Assumptions

- It is assumed that the existing wood and pulpwood industries require an ongoing supply of raw material broadly at or above the present level and that imports can make up shortfalls.
- With regard to importation, it has to be borne in mind that forest disease control requirements may restrict potential sources of supply.

- It is assumed that to achieve best economy of scale, to redress somewhat the CO_2 derived from peat production and to eke out the peat resource within reasonable reach of the stations, forest wood, wood residues and wood coproducts augmented by appropriate short rotation coppice could be cocombusted with peat at the three new fluidised bed plants in the Midlands.
- It is assumed that up to 30% of the fuel mix can be derived from these woody resources based on trials made at Edenderry.
- It is assumed that the necessary market mechanisms can be put in place to bring these fuels on stream as required and that the current short planning permission (15 years) attached to these plants will be extended.

6.5 Resource Availability

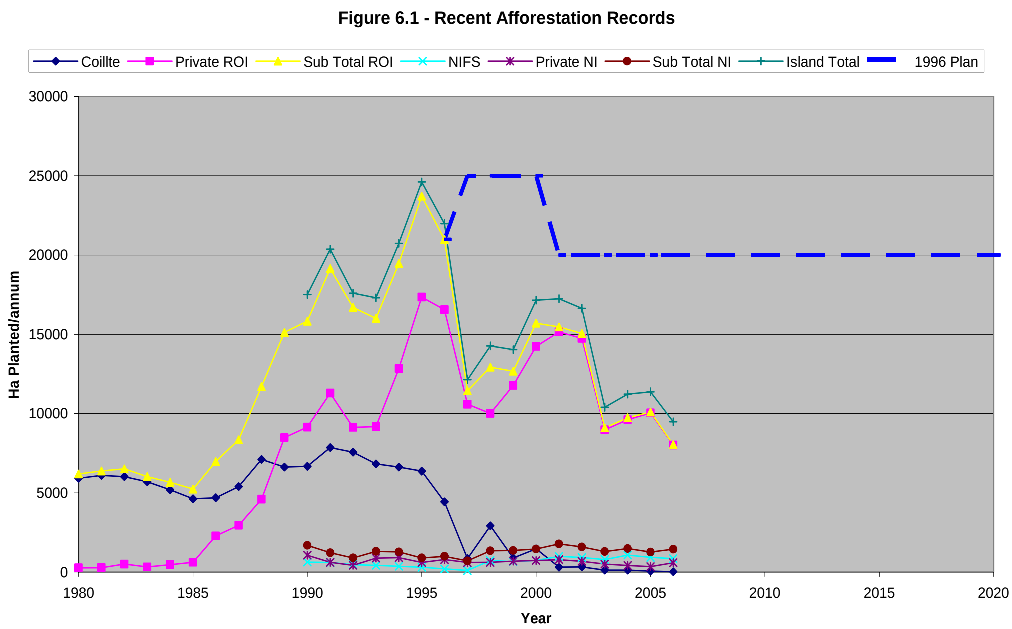


Figure 6.2 - Afforestation Aggregate Planting Since 1996 - Hectares

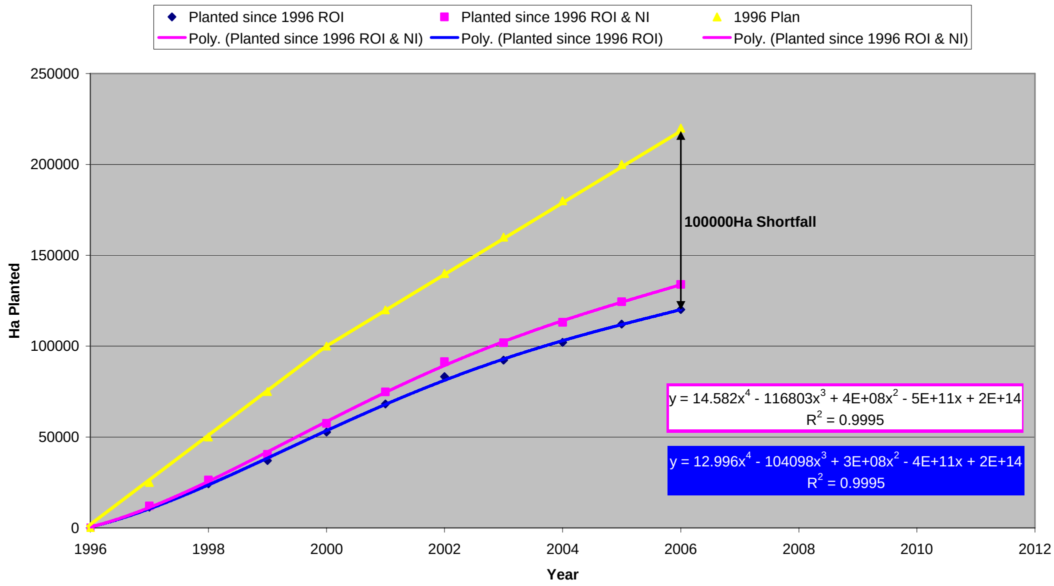


Figure 6.3 - Projected Biomass Required for Heat Market

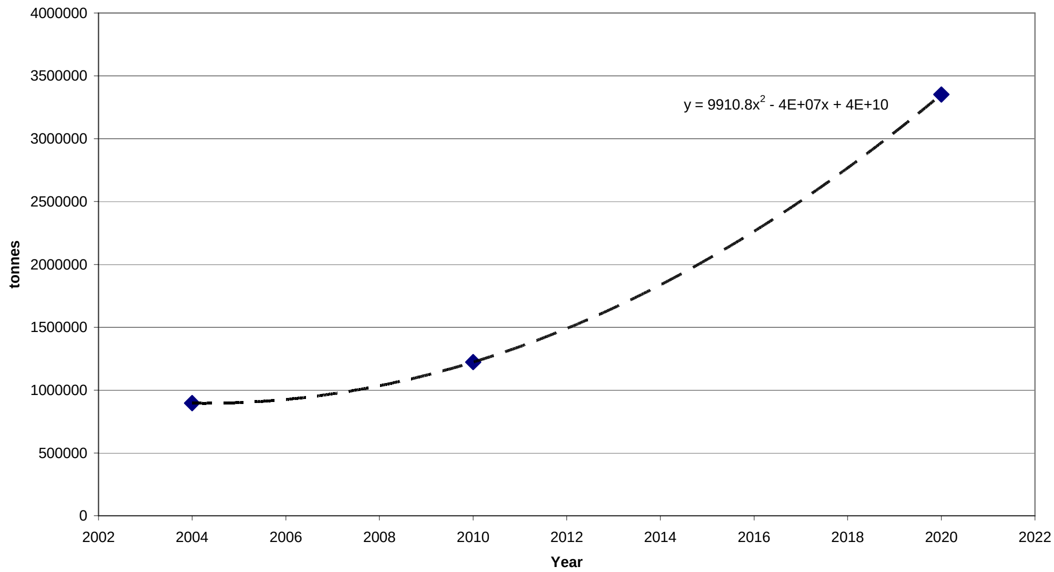


Figure 6.4 - Sustainable Pulpwood fuelled Power Capacity as a function of Annual Private Sector Planting (ROI)

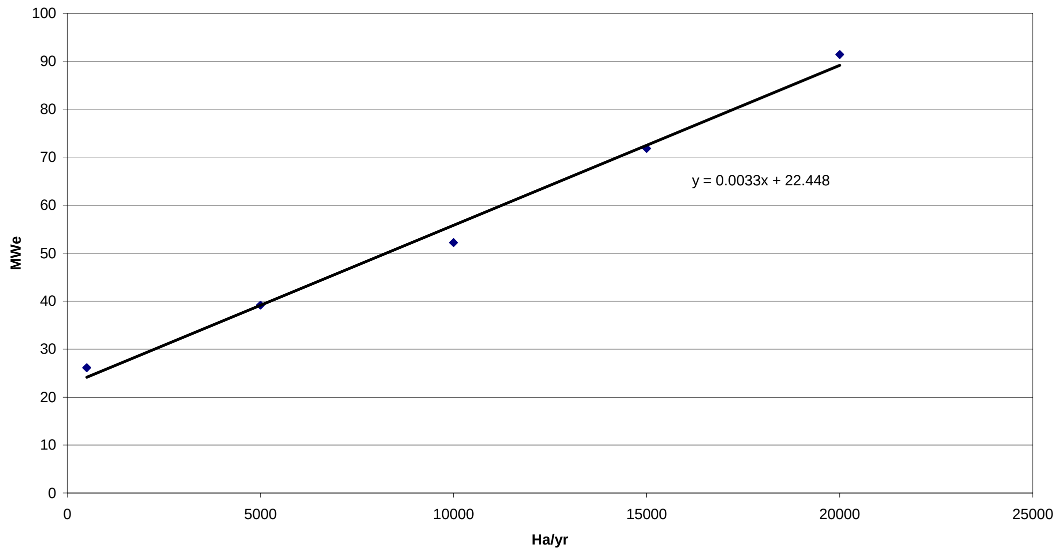
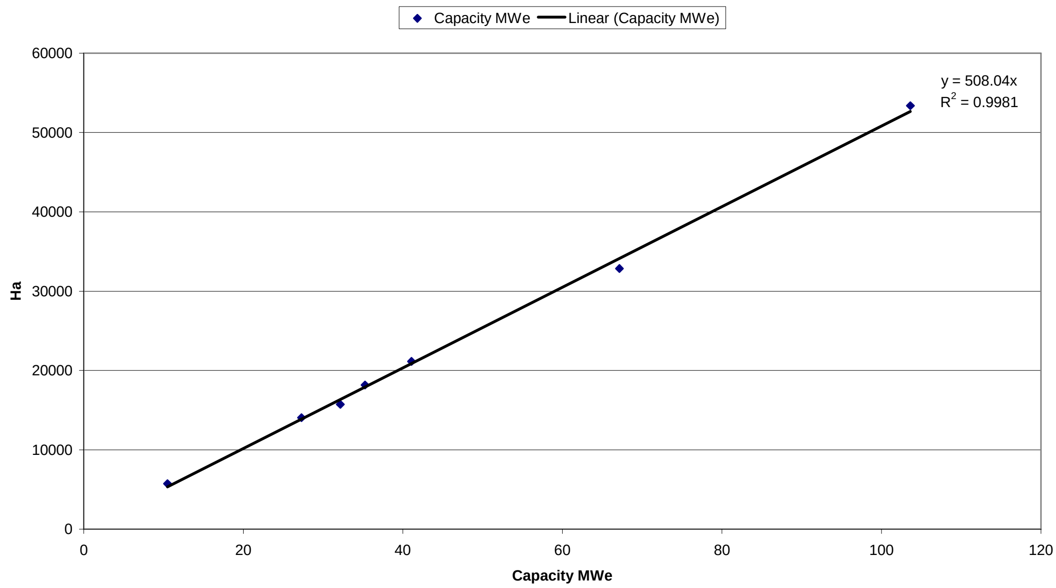


Figure 6.5 - Short Rotation Coppice Area as a function of Cofiring Capacity



6.5.1 Wood Based Heat Sector

An important factor to be considered is the projected development of biomass input to the all island heat market going forward. Both North and South, initiatives have been put in place to facilitate the installation of pellet and chip fuelled appliances at domestic and institutional levels and take up has been strong. There is a corresponding development on the supply side with players seeking to establish an early position based on imports in the absence of sufficient home produced material. Forward projections focus on substitution of fossil heating fuels by biomass, targeting a 5% level by 2010 and 12% by 2020 Ref. (63).

Based on the data of Ref. (62) this suggests, allowing for the same rate of growth in the heating market between 2010 and 2020 as is projected between 2004 and 2010, (75.3ktoe = 347,973t/yr) that the biomass requirement for 2020 will have reached 3,351,627t/yr (at 50% moisture content) coming simultaneously with the projected cocombustion projections it gives some feel for the level of imports that may be necessary.

6.6 Cost

The levelised costs per KWhe of this resource are based on projected capital and operating/maintenance cost inputs as detailed in this section and in the corresponding appendix.

Table 6.1

Key Attributes used in the Determination of Incremental Levelised Cost of Biomass fed Cocombustion Projects

Attribute	**Relevance to Indicative Levelised Cost**
Installed Capacity	Rating of biomass fuelled installation
Annual Energy Yield	Calculated from characteristics of supplied biomass, consumption, capacity factor, efficiency
Location of Site Reference Point	The two sets of coordinates provide indicative length for overhead line to the nearest network connection point which in turn has a cost implication for the site. (Applicable to Tawnaghmore only)
Location of nearest available terrestrial 110kV station	

Table 6.2

Projected Cost Base for Development, Operation and Maintenance of Biomass Fed Cocombustion Projects

Item	Description	Unit	Rate €k
1.	Wood Cocombustion Plant	Sum	
2. 2.1 2.2	Overhead Line * End masts OH Line (Factor 1.15)	 Number Km	 Included in apportioned cost
3. 3.1 3.2 3.3	Receiving 110kV Station * Apportioned share of Upgrade Metering MV Cubicles	 Sum Sum Sum	 Included in apportioned cost “ “
4. 4.1	Operation & Maintenance % of Total Capital Cost/yr	 %	 Varies

(* Applicable to Tawnaghmore only)

Table 6.3

Items included under each cost heading (Biomass Cocombustion)

	Cost Heading	Items
1.	Wood Cocombustion Plant	Design/Construction/Installation of biomass fed facility in compliance with applicable specifications, codes, standards, and regulations at designated site, including fuel, reception, storage, processing and feed system, ash disposal system, access roads, laydown and parking areas. Fuel handling, storage, reclamation, size, reduction, weighting, feed and, where appropriate, separate ash handling and disposal (incl. marine facilities as appropriate)
2.	Overhead Line *	33/38/110kV overhead line rated for appropriate load between end masts at generator and receiving 110kV station in compliance with TSO/DSO specification and regulatory requirements (including testing and commissioning).

	Cost Heading	Items
3.	Receiving 110kV Station * Upgrade	Provision of additional compound space, bays, busbars, founds, structures, ducts, circuits and equipment as are required to meet TSO/DSO specifications and requirements including testing and commissioning.
4.	Annual O&M	Land lease/wayleave rentals, infrastructure maintenance, electrical imports, TUOS, operations, grid maintenance, insurances, insurances, rates and levies, spares, reserves, and contingencies.

(* Applicable to Tawnaghmore only)

Table 6.4

Summarised Cocombustion Cost Base

Station	Biomass Element MWe	Incremental Capital Cost €M	Annual O&M €M	Projected Annual Output GWhe
Moneypoint	107.2	30	53.7	798.2
Kilroot	32.2	15	16.7	239.4
Edenderry	36.5	8	17.1	271.4
West Offaly	40.8	9	19.9	303.8
Lough Ree	28.2	7	13.9	209.9
Tawnaghmore *	33.2	48.1	15.7	206

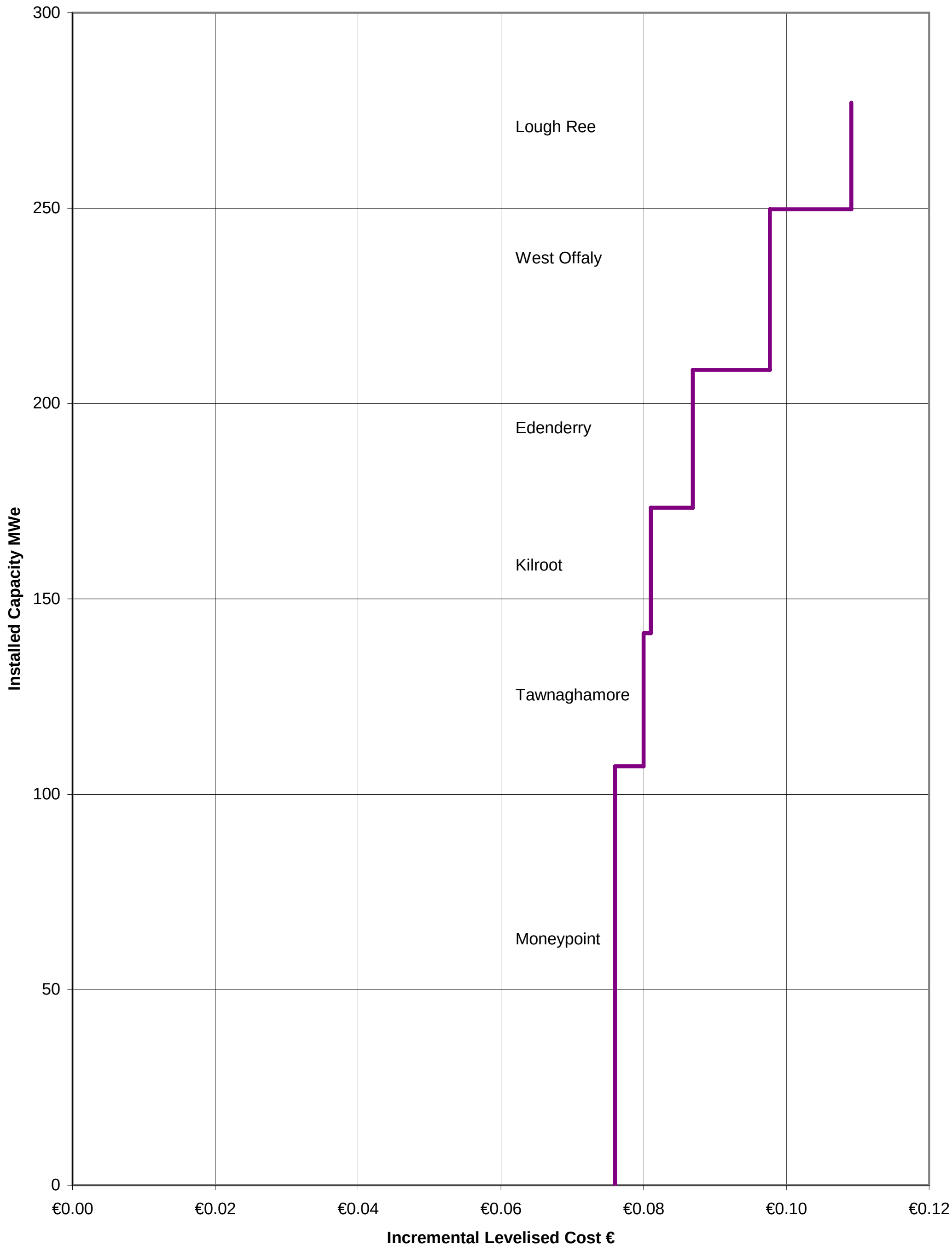
* Costs at Tawnaghmore are apportioned from quoted cost of projected new development (Ref. 65). Costs at other stations are predesign incremental estimates only.

Table 6.5

Projected Cocombustion Levels and Incremental Levelised Cost

Plant	Installed Capacity Mwe	Portfolio	Levelised Cost €/kWhe
Edenderry	35.25	1-6	0.09
Lough Ree	27.3	1-6	0.11
West Offaly Power	41.1	1-6	0.10
Tawnaghmore	34	5 & 6	0.08
Kilroot	32.16	5 & 6	0.081
Moneypoint	107.2	6	0.076

Figure 6.6 - Biomass Resource Cost Curve Portfolios 1- 6
(Co-Firing only - 277MW)



6.7 Conclusions

(1) There is a developing competition for land availability between potential uses that reflect biofuel production for transport, afforestation for the timber industry and, with short rotation coppice, for heat and electricity production. This is brought into sharper focus by the requirements of extensification and biodiversity and the prospect of a return to grain production.

(2) It appears that the needs of the Irish timber industry will be broadly met by the production of the state forest sector.

(3) For sustainability the minimum annual plantings level required by the private sector is 10,000Ha/yr which would support about 55MWe capacity if all the resulting pulpwood could be devoted to this purpose. Clearly transportation cost alone would make this well nigh impossible.

(4) Recourse must then be had in the first instance to short rotation coppice where the provision of 50,000Ha could fuel 100MWe capacity. These two sources should then be able to supply the three Midland peat fired stations to 30% capacity (circa 103MWe), as required for Portfolios 1-4, although the estimated marginal levelised costs at 0.09 – 0.1€/kWhe outweigh those of the stations nominated for Portfolios 5 and 6 (Moneypoint, Kilroot, Tawnaghmore).

(5) Tawnaghmore would most likely draw part of its biomass supply from the same pool as Lough Ree and possibly West Offaly stations in particular.

(6) Moneypoint and Kilroot having marine terminals are better placed to import biomass in bulk than any of the other stations and show apparently better marginal levelised costs than other stations except the purpose built Tawnaghmore.

(7) It must be borne in mind that the final levelised costs would be dependent on numerous operating and design requirements at all of these stations, none of which are available at the time of writing. The figures quoted must therefore be used with caution.

(8) Finally the increase in biomass input to heat market, projected at 12% in 2020 has implications for the power sector.

7 Small Hydro and Solar Photovoltaic

7.1 Small Hydro

A total of 904 potential small hydro possibilities were examined during the course of the study (743 in the Republic and 161 in Northern Ireland).

The total technical power resource was an impressive 99.15MWe but average size of project was only 0.11MWe (range 2.63MWe down to 0.002MWe) and many of these projects were located in areas remote from the 110kV network. In general the small scale of the potential projects meant that network connection would be at low or medium voltage level and that there would be very low incremental generation from hydropower at any 110kV node, thus placing them outside the scope of this report in terms of fulfilling portfolio obligations.

7.2 Solar Photovoltaic

At the outset of this project it had been planned to include a module projecting grid connected solar photovoltaic (PV) capacity to 110kV nodes for 2020.

A number of grid connected solar PV installations exist primarily for research, development and demonstration purposes around the world, including the EU where extremely active research programmes of the past decade have shown significant reductions in unit costs with improved performance in photovoltaic components, economy of scale in production and increased scale of installations, particularly in Southern Europe and areas with higher solar radiation and clearer (cloud free) skies than Ireland.

However, as in the case of small hydro, it was concluded that there would be very low incremental generation from solar photovoltaic power at any 110kV node by 2020 and that special inclusion of this heading was unnecessary at this stage as the presence or absence of a few MWe of solar P/V. derived power at a node was unlikely to influence the modelling being carried out by the other work streams to any significant degree. It was therefore agreed to focus on the other renewable energy resources for the purpose of meeting portfolio requirements by 2020.

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Appendix 1

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G. McCarthy (Coillte)
E. Egan (Coillte)
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Appendix 2

Biomass : EU Action Plan

A2.1 Introduction

The issue of whether biofuels should be used for electricity generation heat or transport centres on the reality of available market choice.

In addressing the dilemma posed by these options for biofuel production and utilisation it is useful to consider the Biomass Action Plan (Ref. 21) as communicated by EC in December 2005. Given that energy is recognised as being key to helping Europe achieve its objectives for growth, employment and sustainability and that high oil prices have focussed attention on the increased dependency on imported energy it has been necessary to carry out a comprehensive energy policy review in respect of competitiveness, sustainability, security of supply. The outcome highlights the need to:

- Reduce energy demand
- Increase reliance on renewables given the potential to produce them domestically and sustainably
- Diversify energy sources
- Enhance international co-operation

Given that biomass can have advantages over some other renewable energies e.g. relatively lower costs, less dependence on short term weather changes, promotion of regional economic structures and provision of alternative income possibilities for farmers, the Biomass Action Plan seeks to identify a co-ordinated approach to biomass policy. By 2010 it is projected that this could, without environmental damage

- Diversify Europe’s energy supply reducing reliance on energy imports from 40% to 42%.
- Reduce GHG emissions by over 200Mt CO_2 (eq)/yr.
- Provide direct employment, mostly in rural areas, of over 250,000 persons
- Introduce some softening of mineral oil price
- Enhance EU technological development.

A2.2 Biomass Use in Transport, Electricity and Heating

Liquid biofuels being the only direct substitute for mineral oil in transport have a justifiably high political priority in an era of rapidly rising prices in this sector.

The use of biofuels although a relatively expensive way of reducing CO_2 emissions in this expanding sector is one of the few that is available. Transport fuels have the highest employment potential and greatest security of supply benefits.

Biomass use in heating is the cheapest option as it relies mainly on wood and wastes but is the slowest growing option although the availability of easy to handle pellets should change this if market confidence can be fostered. District and institutional heating can be more easily developed than individual heating and a number of measures are contemplated with a view to facilitating use of biomass in heating.

The use of biomass in electricity production brings the greatest benefits in terms of greenhouse gas abatement. It also relies mainly on wood and wastes and up to 2010 major competition between the three usages is not foreseen. If ‘second generation’ biofuel production processes come on stream from then, competition may arise for lignocellulose (woody) materials. These will arise from forest waste, industrial wood waste, forest pulpwood and some energy crops – SRC (willow) and Miscanthus.

A2.3 Transport Biofuels

Implementation of Directive

The Biofuels Directive had set reference values of a 2% (in energy terms) market share for biofuel in 2005 and 5.75% for, 2010. The 2% value was not met. A report is due in 2006 on the directives implementation that will address issues such as

- National targets
- Using biofuels obligations (instead of tax exemptions)
- Ensuring that, via a system of certificates (applicable to both domestically produced and imported biofuels), only biofuels whose cultivation complies with minimum sustainability standards will count toward these targets.
- The EU favours a balanced approach to the issue of domestic production versus imports. It will propose
    - Amendment of EN standard 14214 to permit use of a wider range of vegetable oils in biodiesel
    - Ensure that market access for imported ethanol is at least as good as provided for in current trade agreements with non EU procedures.
    - Support developing countries that wish to produce biofuels
    - Maintain a balanced approach vis a vis domestic producers and external trading partners.

Although Europe has a greater capacity to produce bioethanol than biodiesel, using less land with better potential to reduce cost via economy of scale, its vehicle fleet has a higher proportion of the more efficient diesel engines. The Commission will encourage production of ethanol (and its importation) including its use in modified diesel engines to reduce demand for diesel.

Although reform of CAP has led to an allowable energy crop payment of €45/Ha it is recognised that decisions as to the appropriate energy crops to grow are best taken at regional or local level.

About 35% of the annual growth of wood in EU forests is not used for variety of reasons and the Commission is preparing a forestry action plan to be adopted in 2006 that will address energy use of wood and wood residues.

Waste is also an underused energy resource and a number of revisions to waste framework legislation are in contemplation, including the regulatory framework for the authorisation of use of animal byproducts for energy recovery, and production of new standards for solid biomass.

The Commission also encourages the development of national biomass action plans with a view to fully taking into account the benefits of biomass. The numerous measures proposed in the biomass action plan underwrite the above points and are formalised in the EU Strategy for Biofuels (2, 2006) Ref. (22).

A2.5 Electricity Production

Electricity can be generated from all types of biomass either in freestanding power stations or cofiring with coal, peat etc. in large central stations. Where possible maximum benefits should be pursued by utilising the heat produced as well. Smaller decentralised plants often have localised advantages for environment and rural development, having regard to biomass availability, transport, grid connection and local labour input. Of the total arable land resource of 97MHa available in the 25 EU member states only 1.8MHa were used for producing transport biofuel materials in 2005. The use of 'second generation' biofuels based on lingo cellulose is not projected to reach any significant level until after 2010 although a number of pilot and demonstration plants are operational.

A2.6 Conclusions

(1) The action plan must be considered as an indicative document that will be subject to further development

(2) Given that the Biofuels Directive was not met, a report is now due indicating the measures that it will be necessary to adopt going forward.

(3) A forestry action plan is also due for issue this year. It appears that forestry may be one area where Ireland can can push forward vigorously.

(4) Rethinking some of the restrictions that apply to wastes has some potential for increasing the recognisable energy value of this resource which could have implications in the areas of biofuel and heat/power.

(5) Present indications suggest that in the medium term forest biomass and SRC will be the bulk material of choice for cofiring in the power industry, when within economic range of the stations.

(6) Other types of biomass will find outlets in Biofuels and locally resourced heat or CHP applications.

A2.7 Recommendations

(1) The above conclusions should be borne in mind when making projections of the biomass resource likely to be available for power generation in the period to 2020 and beyond.

Appendix 3
Biomass : An EU Strategy for Biofuels

A3.1 Introduction

Within EU, transport is responsible for 21% of all GHG emissions and the percentage is rising. It is essential to moderate this in light of the Kyoto Protocol. Nearly all the energy used in this sector is oil and comes from a relatively few parts of the world. Developing countries are even more vulnerable. The possible role of biofuels in reducing this dependency is considered with the objectives of reducing GHG emissions, boosting the decarbonisation of transport fuels, diversifying fuel supply sources and developing long term replacements for fossil oil.

The EU Strategy Ref. (22) for biofuels has three aims:

- Promote biofuels in EU and developing countries, ensuring that their production and use is globally positive for the environment and that they contribute to objectives of Lisbon Strategy.
- Prepare for large-scale use of biofuels by improving their cost competitiveness through optimised cultivation of dedicated feedstocks, research into 'second generation' biofuels, support for market penetration by demonstration projects and removal of non-technical barriers.
- Explore opportunities for developing countries in the production of biofuels and their feedstocks and identify possible EU role in supporting development of sustainable biofuel production.

The EU is currently a net importer of diesel while it exports petrol. With the technologies currently available EU produced biodiesel breaks even when oil prices reach €60 per barrel while the corresponding figure for ethanol is €90 per barrel. Encouraging the use of currently available biofuels is seen as an intermediate step in reducing GHG emissions and diversifying transport energy sources while leading towards other alternatives in the transport sector that are as yet immature.

The main second generation technology prospects are lingo-cellulosic processing (3 current EU plants) biomass to liquid biofuels (FT) and biodimethylether (2 current EU plants). Synthetic natural gas can also be produced from renewable resources. All of these systems while technically possible are only at the pilot or demonstration stage in commercial terms. Progress will be monitored at EU level with a view to providing support, when appropriate, for upgrading from demonstration to commercial scale where the environmental benefits of these processes can be guaranteed. Non technical barriers to their acceptance must be removed.

As biomass productivity is highest in tropical environments and production costs together with fossil energy inputs are relatively lower, there are mutual advantages in using material from these sources particularly where ethanol is concerned. EU is currently the principal producer of biodiesel. There are socio-environmental concerns regarding the large scale expansion of feedstock production in some of the developing countries.

A3.2 Biofuel Strategy

The Commission has identified seven policy areas under which it will promote the production and use of biofuels. These are

(a) Stimulation of Demand

The Biofuels Directive may be revised to set national targets for market share of Bofuels, using biofuels obligations (as a possible alternative to taxation measures) and ensuring sustainable production. Member states would be encouraged to give favourable treatment to second generation biofuels in the obligations. A framework for incentives linked to the environmental performance of individual fuels would be established and their use in public, private transport fleets and marine applications encouraged by a variety of measures.

(b) Capture of Environmental Benefits

This will involve quantification of the extent to which biofuel use reduces CO_2 and GHG emissions relative to targets, ensuring the sustainability of biofuel feedstock cultivation in EU and third countries. Some of the technical limits on biofuel concentrations and characteristics will be reviewed. It is essential that appropriate minimum environmental standards apply to feedstock production for biofuels, including fitting of biocrops into rotations, sustainability under CAP reform and compliance with World Trade Organisation rules.

(c) Development of Production and Distribution of Biofuels

Memberstates will be encouraged to take account of the benefits of biofuels/bioenergy in preparing operational plans under cohesion and rural development policy headings. The basis and technical justification of practices that act as barriers to introduction of biofuels will be sought and monitored as will possible effects on traditional markets for these materials.

(d) Expansion of Feedstock Supplies

Sugar production for bioethanol will be eligible for both the ‘non-food’ regime on set aside land and the energy crop premium €45/Ha. Additional cereals may be released from intervention stocks for biofuel production thus reducing cereal exports with refunds. A Forestry Action Plan, a key part of which is energy use of forest material, will be brought forward, animal byproducts legislation will be reviewed to facilitate use of this material in biofuels. Standards for the secondary use of waste materials will be clarified. The impact of biofuel demand on availability and pricing of commodities and by-products will be monitored. An information campaign on the opportunities for energy crops will target farmers and forest owners.

(e) Enhancement of Trade Opportunities

Separate nomenclature codes for biofuels will be considered. Existing market access conditions for imported bioethanol will be maintained or bettered. A balanced approach will be taken in future trade negotiations in the context of a rising demand for biofuels. The biodiesel standard EN14214 may be amended to facilitate the use of a wider range of feedstocks (including ethanol) in biodiesel production.

(f) Support for Developing Countries

The EC will ensure that countries affected by EU sugar reform can use support measures for development of ethanol production. A coherent biofuels Assistance Package will be prepared for use in developing countries having biofuel potential. Regional biofuel action plans and national platforms will be considered for where appropriate.

(g) Support for Research and Development

The 7th Framework Programme will provide options for support of the industry. Priority will be given to the bio-refinery concept and for second generation biofuels. Industry led biofuel technology platforms and the strategic research needs identified by them will be supported.

A3.3 Conclusions

(1) The initial conclusion has to be one of disappointment at how little of the EU transport fuel demand and that of Ireland in particular, can be satisfied from within its own resources.

(2) A revision of the Biofuels Directive is likely to incorporate lessons learned from experience to date.

(3) The use of relatively short term taxation measures may be more widely replaced by biofuels obligations to bring longer term confidence to the market.

(4) As ethanol is a more widely traded fuel than biodiesel, and one which the EU has greater potential to produce or to trade in (despite the fact that the European vehicle population is predominantly a diesel engined one), consideration is being given to encouraging greater numbers of ethanol powered or multi-fuelled vehicles in the market place.

(5) Various measures are likely to be brought forward to support ethanol production in developing countries with a view to increasing imports into EU. While a ‘level playing field’ is to be maintained for EU farmers this is much more likely to favour those in the large grain producing countries of central Europe where economy of scale can prevail than in smaller countries like Ireland.

A3.4 Recommendation

(1) The above conclusions should be borne in mind when making projections of the biomass resource likely to be available for power generation in the period to 2020 and beyond.

Appendix 4

Biomass : Environmental Constraints on Biofuel Production

A4.1 Introduction

The general issue of biomass production and utilisation covers a wide range of purpose grown crops, materials and wastes which are amenable to different processes and end uses. All of these are subject to often conflicting commercial socio-economic and environmental pressures which make it rather difficult to project forward the likely extent and utilisation of these multiple resources in electricity production.

An attempt has been made Ref. (23) to quantify, on an EU wide basis, the amount of biomass that could technically be available for energy production without increasing pressures on the environment. It is clear that corresponding assessments on a local or member state scale would be necessary to take local conditions more fully into account. In the absence of such work there is always a danger that a global overview becomes crystallised as universal fact leading to over arching constraints that may hinder local opportunities to respond effectively to local needs.

The environmental assumptions used in the study were:

- At least 30% of agricultural land is dedicated to 'environmentally oriented farming' in 2030 in most member states i.e. REPS (scheme)
- Extensively cultivated agricultural areas are maintained: grassland is not transformed into arable land.
- Approximately 3% of intensively cultivated agricultural land is set aside for establishing 'ecological compensation' areas by 2030.
- Bio energy crops with low environmental pressures are utilised.
- Current protected forest areas are maintained; residue removal or complementary fellings are excluded in those areas.
- Forest residue removal rate is adopted to local site suitability. Foliage and roots are not removed.
- Complementary fellings are restricted by an increased share of protected forest areas and dead wood.
- Ambitious waste management strategies are applied.

It is further assumed that the main factors driving the increase in bioenergy potential are productivity increases and assumed 'liberalisation' of the agricultural sector which results in additional area becoming available for dedicated bioenergy farming. Increased carbon and fossil fuel prices are assumed to make bioenergy feedstock more competitive over time compared with traditional wood industries or food crops. However it is assumed that bioenergy crops should not be grown at the expense of food crops for domestic EU supply. It is suggested that to ensure that bioenergy production develops in an environmentally compatible way environmental guidelines need to become an integral part of the planning process at local and other levels and that national Biomass Action Plans could be a first step in this direction so that bioenergy production can be steered in the right direction.

It is suggested that in the short term the largest potential for bioenergy comes from the waste sector (100Mtoe) which is supposed to remain essentially constant to 2030. This includes agricultural residues straw, wet manure, wood processing residues, biodegradable municipal solid waste.

It is projected that the exploitation of renewable energy resources can help EU meet many of its environmental and energy policy goals including

- Obligation to reduce greenhouse gases under Kyoto Protocol
- Reduce energy import dependency

Thus indicative targets for 2010 have been set for the share of renewable energy in total (12%) and in electricity production terms and also in biofuels in transport. Discussions on more stringent targets beyond 2010 are under way.

The referenced report aims to broadly model the bioenergy potential in a consistent way for agriculture, forestry, and waste. The results indicate the environmental aspects that should be looked at when increasing bioenergy production and how much bioenergy will be available without harming the environment or counteracting current and potential future EU environmental policies and objectives. However it states that without the correct safeguards, even a significantly lower exploitation could lead to increased 'environmental pressures'.

The term 'environmentally-compatible potential' of bioenergy is defined as the quantity of primary biomass that is technically available for energy generation based on the assumption that no additional pressures on biodiversity, soil and water resources are exerted compared to a development without increased bioenergy production (and in line with other current and potential future environmental policies and objectives, which are admitted to be uncertain!).

It is assumed that, beyond Kyoto, EU GHG emissions would be 40% below 1990 level by 2030 with CO_2 permit prices reaching 30€/t in 2020, 65€/t in 2030. This would imply an oil cost of 62€/barrel in 2030 and a swing from competing users of forest pulpwood or competing food exports. In North Western Europe climate change is not likely to have a significant negative effect on biomass production apart from possible storm damage to some crops. In the long term bioenergy crops from agriculture provide the largest potential, driven by additional productivity increases, liberalisation of agricultural markets, and introduction of high-yield bioenergy crops. While the environmentally compatible bioenergy potential from agriculture is projected to triple on an EU wide basis by 2030, the bulk of this is projected to occur in only six large states (incl. UK). Ploughing up of 'extensively used' grassland into arable land is disapproved of on grounds of biodiversity reduction and soil carbon release. This particularly affects Ireland because of its high proportion of grassland. EU wide, the available 'environmentally compatible' arable land is projected to rise by 50% by 2030. As bioenergy crops are optimised for energy rather than food, the use of perennials and double cropping can combine diversity, high yield and reduced environmental pressures. Perennial crops and short rotation forestry have less impact on soil compaction/erosion, nutrient inputs to soil and water, pesticide pollution and water abstraction.

It is suggested that while the environmentally compatible bioenergy potential from forestry remains largely constant to 2030 (40Mtoe) an additional amount is released from competing industries as a result of increasing energy and CO_2 permit prices which will increase the market value of wood. (This may threaten some pulpwood users).

While environmental considerations in most cases restrict the technically available amount of biomass from waste, agriculture and forestry it is suggested that there can be some co-benefits between biomass production and conservation e.g. reduction of fire risk by removal of forest residues, utilisation of cuttings from extensive grassland, use of multiple cropping and perennials, ultimately use of ligno cellulose.

A4.2 Agriculture

It is suggested that the increased intensity of farming over the past fifty years, attributed in part to the Common Agricultural Policy, has had negative environmental impacts including water pollution by particles, nitrates, phosphates and pathogens accompanied by habitat degredation and species loss, over abstraction of water for irrigation and substantial GHG and air pollutant emissions. It is suggested that the demands of bioenergy crops may create further competition for land and water between existing agricultural activities, energy production and needs of conservation and urbanisation. It is suggested that the environmental impact of bioenergy production is largely a function of selection of production areas, particular crops cultivated and farming practice.

The amount of agricultural biomass that can be used to produce energy is primarily determined by the land area available and by the yield of the bioenergy crop cultivated on this land. The projected environmentally compatible bioenergy potential from agriculture was then calculated via a four step process which

- Formulated “environmental criteria”
- Modelled future land availability for each member state in 2010, 2020, 2030 subject to these criteria
- Determined an “environmentally compatible” crop mix for each environmental zone in EU
- Estimated the bioenergy potential in each member state based on the above.

The environmental criteria utilised were:

1. At least 30% of the agricultural land (it is noted that Ireland/UK are already at this level) in most member states is dedicated to ‘environmentally oriented farming’ (high nature value or organic). Low Yields are an inherent characteristic of most HNV farming systems.
2. 3% of currently intensively cultivated agricultural land is set aside by 2030 establishing ‘ecological compensation’ areas in intensive farming areas (both of these criteria affect the entire utilised agricultural area and were introduced to prevent increasing bioenergy production from affecting an ‘environmentally favourable’ development of the agricultural sector).

3. Extensively cultivated agricultural areas e.g. grassland (!) are maintained when released from food/fodder production (i.e. the 5% and 10% limiting rules on plough-up apply) and is seen as a way of preventing a switch to lingo-cellulose crops on land that is suboptimal for arable cropping, and also prevention of soil carbon release through ploughing. It is however recognised that appropriate biomass cropping on grassland is better than abandonment.
4. Biomass crops with low environmental impacts are used. These should minimise soil erosion by maintaining year round soil coverage, avoiding tillage on steep slopes, providing wind breaks and reducing organic loss in soil, (sugar beet provides little protection against erosion, it and potatoes have a high harvesting weight contributing to soil compaction and rutting). Pesticide and fertiliser use may be high (as with oil seed rape) leading to potential leaching to waters. Certain cereals or perennials may have lower input requirements or better rotation impact. Perennials and SRF crops can enhance biological and landscape diversity. Crops with low fire spreading characteristics are also a consideration.

As modelled for the EU as a whole the amount of arable land available for dedicated bioenergy production increases from 13MHa 8% UAA (2010) to 19.3MHa (2030) 12% UAA.

Available grassland/Olivegrove will increase from 1.7Ha (2016) to 5.9MHa (2030) but should not be ploughed and only mown grass can be used for bioenergy. This figures include a transfer (for France & Germany) of some 5m Ha (2030) land currently producing food for export to production of bioenergy due to anticipated high fossil fuel and carbon permit prices.

The projections show the UK having land availability for dedicated crop cultivation by Member State of 824, 1118, 1584 x 10^3ha for the years 2010, 2020, 2030 while Ireland has none for any of these years. The new EU (8) member states alone deliver about 50% more arable area for bio energy than the EU14 in each of these years. The reason that Ireland fares badly relates primarily to its high proportion of grassland and countries with intensive farming systems e.g. Denmark, Holland, Belgium also suffer, due to environmental demands for intensification. (It is expected that new member states will ‘export’ part of their production internally to the EU14).

A4.3 Environmentally Compatible Crops

The crop mix is expected to change radically over time with SRF and perennial energy grasses replacing oil and starch based crops having lower energy yield and higher environmental pressures. (This of course assumes that advanced ‘second generation’ biofuel conversion technologies become commercially viable from about 2010). Further advanced conversion in the biogas field is projected from about 2020 which will facilitate conversion of biogas crops such as maize, cereals, oil crops, mown grass, perennial grass, some of which would form part of the necessary multi-annual rotational pattern of crops (including food/feed crops) along the Atlantic margin.

It is recognised that the work was only a first approximation based on statistics at national level and that many of the variables are subject to more localised refinement.

Table A4.1

Prioritisation of Annual Crops in Atlantic/Central Zone in Qualitative Environmental Pressure Terms

	Erosion	Soil Compaction	Nutrient Inputs	Pesticides	Water Demand	Fire Risk	Biodiversity Formulated	Crop Type Diversity
Double Cropping	A	A	A	A	A/B	-	B	A
Linseed	A	A	B	A	A	-	A/B	A
Other Cereal	A	A	A	A	A	-	B	B
Grass	A	A/B	B	A	A	C	A	A
Clover	A	A/B	B	A	A	-	A/B	A
Hemp	A/B	A	A	A	B	-	B	B
Wheat	A	A	A	A	B	-	B/C	C
SRC	A	A	A	A	B	-	A/B	
Sun Flower	B/C	A	A/B	B	B	-	A/B	B
Rapeseed	B	A	B/C	C	B	-	B/C	A/B
Sugar Beet	C	C	B	B	B	-	B	B
Potatoe	C	C	B	B	C	-	B/C	A/B
Maize	C	B	C	C	B/C	-	B/C	B/C

A: Low Risk B: Medium C: High Risk - Not relevant

A4.4 Bio-Energy Potential From Forestry

All forests even monoculture plantations are reservoirs of biodiversity. Forestry in Europe (30% of land area) extracts at a rate not greater than the increment in growing stock. 'Complementary' felling is the term used to describe the difference between maximum sustainable harvest and the (usually lower) roundwood demand. Biomass residues (stem top, foliage, stump and root) are also considered but has a much lower economic value than the former (SRC is treated as agriculture). The amount of large diameter deadwood per hectare left behind is considered an important factor in ensuring biodiversity in forests. The highest levels of nutrient concentration occur in foliage and small branches and to avoid need for compensatory fertilisation these are usually left on site. However extraction of logging residues also removes nitrogen nutrients which can have a positive effect on forest lands where the nitrogen loading is already high.

Logging residues reduce the potential for soil erosion and act as regulators of surface water movement and quality.

The following criteria were framed to avoid increasing environmental pressure due to bio-energy production from forestry.

- No intensification of use on protected forest areas
- Foliage and roots to be left on site (extraction 60%, 40%, 12% of residual biomass)
- Extraction rate for stem and branch residue to be limited relative to site suitability
- For complementary fellings an increase in protected areas (currently 11.7% of European forests) by reducing existing available area for wood supply by 5%
- A further 'set aside' of 5% of wood volume as individual or small groups of retained trees to increase deadwood availability.

A4.5 Waste

1.8 billion tonnes of waste is created annually in Europe. Overall annual waste levels are in fact rising despite years of effort directed at curtailment and reduction. A significant proportion is bio-waste which can be used to generate energy. Bio-waste may be taken to comprise

- Solid agricultural residues: straws, stalks, prunings
- Green agricultural residues, leaves from potatoes and beet
- Wet and dry manure from animals and poultry
- Biodegradable fraction of MSW (kitchen/garden/food/paper/card)
- Wood processing waste, saw dust, offcuts from wood industry
- Construction/demolition/packaging wood waste
- Household waste wood, furniture, fencing
- Sewage sludge
- Industrial Food Wastes: Dairy/Sugar/Beverage Production

The approach taken seeks to ensure that increased bioenergy demand does not counteract aims of waste reduction and is consistent with the environmental criteria used in the agricultural and forestry sections.

Future diversion of biowaste away from landfill seeks to allow for the focussed treatment of this material to avoid future GHG emissions. Assuming an increase in energy and carbon permit price, the value of bioenergy from waste is projected to increase also.

The following basic environmental criteria were assumed:

1. Ambitious waste minimisation (household waste reduced by 25%)
2. No energy recovery from waste currently being reused or recycled (i.e. 63% of straw, 17% of potato leaves 2% of beet leaves 10-50% of food waste available)
3. All (suitable) household waste currently being incinerated or landfilled (without energy recovery) or composted to be made available for energy production (digestion).
4. Production of wood products (incl. paper) declines in line with nature conservation scenarios.

5. More extensive farm practices reduce the availability of bio-waste (30% of UAA should be environmentally oriented by 2030).

Thus

- The environmentally compatible scenario assumed a 25% reduction in MSW and construction/demolition waste relative to baseline
- For agriculture and food processing waste the scenario was developed from yields based on environmentally oriented (extensive) farming
- For other bio-wastes projections based on current quantities modified by impact of environmental criteria on the main economic drivers for those streams was used.

The estimate bio-waste resource for 2010 (EU-25) is 99Mtoe dominated by straw, wet manure, wood proc. Waste and MSW with a reduction to 96Mtoe for 2020, 30, which allows for smaller livestock populations. The projections show an almost flat total level of biowaste of 100Mtoe to 2030 compared with a rise to ~ 115Mtoe with business as usual scenario. The logic of the approach is to convert substantial quantities of waste from the landfilling, incineration, composting without energy recovery category further up the waste hierarchy. With the rising fossil fuel and projected rise in CO_2 permit prices a transfer of some waste from competing uses to energy production could be anticipated. R. of Ireland stands at ~ 1.5Mtoe by 2030.

A4.6 Overall Results

Substantially increasing the production of bio-energy from agriculture, forestry and waste biomass offers significant opportunities for EU to reduce greenhouse gas emissions and to diversify and secure energy supply, and improve economic possibilities in rural areas. Potential downside environmental pressures can be minimised by growing low impact bio-energy crops, maintaining permanent grasslands and balancing forest residue extraction to local site conditions.

The environmental assumptions underpinning the study having been outlined it is concluded that, on an EU wide basis, a significant amount of biomass can technically be available even if the strict environmental constraints noted are applied. The overall environmentally compatible biomass potential increases from 190Mtoe (2010) to 295Mtoe (2030) compared to 69Mtoe (2003). This is 16% of the EU 25 project primary energy requirements in 2030, compared with a biomass share of 4% in 2003. This would reach the EU RE target of 150Mtoe in 2010, thus avoiding 210Mt CO2 eg. It allows ambitious future r.e. targets beyond 2010 which may require 230-250Mtoe of primary biomass feedstock. Within the EU there are winners and losers, winners would include the states with large arable land areas Germany, France, Italy, Sweden, UK, Poland. Losers would include Ireland due to the preponderance of grassland and low level of forestry.

The environmentally compatible bio-energy potential for Ireland is projected to be (Table A4.2):

Table A4.2

EEA Projected Environmentally Compatible Bio-energy Potential (RoI)

Year	Agriculture Mtoe	Forest Mtoe	Waste Mtoe	Total Mtoe
2010	0.0	0.1	1.0	1.1
2020	0.1	0.1	1.0	1.2
2030	0.1	0.1	1.0	1.3

It is suggested that the potential calculated could save 4-600Mt CO_2 (2030) in direct GHG emissions.

The choice of the bio-energy conversion pathways also determines the environmental pressures of bio-energy production. New technologies and pathways can support a wider range of feedstock and crop diversification.

It is suggested that a policy framework is needed to maximise potential benefits of bio-energy production while avoiding potential environmental drawbacks. As the current biofuels market is largely an artificial one created by Government, this could be managed effectively.

Depending on the primary aim of increasing biomass utilisation, different conversion pathways have their advantages and disadvantages.

Bio-heat and electricity production as well as advanced transport fuel conversion technologies should allow utilisation of a broader range of feedstock than the production of first generation transport fuels using only starch or oil based crops. Action is now required at local, national and EU levels.

A4.7 Conclusions

(1) This document, issued by the European Environmental Agency, gives qualified approval to the scale of operations envisaged on the Biofuels Strategy and Biomass Action Plan. However it warns that even significantly lower levels of production could give rise to increased environmental pressures.

(2) Fortunately the document takes what is admittedly only a first step in identifying the ‘environmentally compatible’ bio-energy potential at European level. Supplementary more detailed investigation will be necessary to quantify the specific resource levels applicable to each country based on the expertise of those working in the particular fields.

(3) In terms of likely biomass resources (even to 2030) Ireland fares particularly badly due to the area of the country that is under permanent grassland where change is opposed on grounds of biodiversity. UK is much better placed but it is unclear how much of its estimated ‘resource’ would be applicable to Northern Ireland.

(4) The danger in this document lies in the possibility that it would be accepted at face value and would remain unchallenged by expert Irish and Northern Irish professional opinion who should be in a better position to determine the exact nature of the resources and their limitations. Leaving the document stand unchallenged could make it difficult for Irish agencies (North or South) to argue for change within an EU context later. This could possibly result in unnecessary sterilisation of Irish resources.

(5) There is a strong dependence on the economic success of ‘second generation’ biofuel production systems post 2010.

A4.8 Recommendation

(1) The above conclusions should be borne in mind when making projections of the biomass resource likely to be available for power generation in the period to 2020 and beyond.

Appendix 5

Biomass: Municipal, Industrial and Agricultural Waste Scenario

A5.1 Introduction

This Appendix provides a basic background scenario to the production and disposal measures that are applied to municipal (including commercial), industrial and agricultural wastes in Ireland.

It introduces underlying factors that influence projected levels of landfill gas recovery, anaerobic digestion and thermal treatment as a means of energy recovery from these wastes.

The potential energy producing processes considered are:

- Incineration of municipal solid waste residues
- Landfill gas utilisation
- Mechanical Biological Treatment of Biodegradable Municipal Waste
- Anaerobic digestion of sewage sludge
- Anaerobic digestion of wet agri-food waste slurries
- Incineration of dry agricultural waste
- Wood waste combustion/pyrolysis/gasification

These are dealt with in the following sections.

A5.2 Biomass : Municipal Waste to Energy : Thermal Treatment

A5.2.1 Introduction

The recovery of energy from the municipal waste stream is a feature of government policy in both the Republic and Northern Ireland. Within the context of overall waste management planning, local authorities have in many cases elected to group into regions in preparing their strategic waste management plans. These plans were subject to review during Summer 2006 and the projections made below are based on the position as currently understood. Concern has been expressed that permitting of significant additional landfill capacity may undermine the economics of waste to energy projects by reducing projected gate fees. The figures given on Table A5.2.6 provide a partial projection of the material that could be available to feed thermal or anaerobic digestion processes in the Republic by 2020. Projected thermal plants are listed on Table A5.2.2 wood waste, where not contaminated, is likely to find outlets in the heating market.

A5.2.2 Northern Ireland

The three regional groups are North West (NW) centred on Derry and having a cross border link with Donegal, South West (SWAMP) centred on Enniskillen and ARC21 covering east Ulster centred on Belfast. Neither NW nor SWAMP have opted to include thermal treatment within their plans but will produce a residue material that could be used as refuse derived fuel. ARC21 however has opted to include thermal treatment and is projecting construction of a waste to energy plant with an electrical capacity of 30MWe for operation from 2012 and reaching 43MWe by 2020. The location will be in the Belfast area where potential sites already exist.

This plant is also recorded on Table A5.2.2. The regional plans are detailed in Refs. 40, 41 and 42.

A5.2.3 Regional Waste Management Groups : Republic of Ireland

The several regional groupings that have produced waste management strategies in the Republic are (Table A5.2.1)

Table A5.2.1

Republic of Ireland : Waste Planning Regions

- Dublin City + County *
- Cork City + County *
- North East (Meath, Louth, Monaghan, Cavan) *
- Midland (Westmeath, Longford, Laois, Offaly, North Tipperary)
- Donegal County
- Kildare County
- Wicklow County
- South East (Waterford, Wexford, Carlow, Kilkenny, South Tipperary) *
- South West (Kerry, Limerick, Clare) *
- Connacht (Galway, Mayo, Sligo, Leitrim) *
- Groupings marked (*) have included thermal treatment in their plans

Counties that have not included thermal treatment with energy recovery e.g. Kildare, Wicklow have indicated an intention to use such facilities in adjoining counties e.g. Dublin, if and when the need and opportunity arises. As noted elsewhere Donegal has cross border links with the NW grouping in Northern Ireland which does not include thermal treatment in its plan but could produce refuse derived fuel for use elsewhere.

In 2004 DOEHLG issued a review of regional waste plans (Ref. 34) in the context of the levels of waste arisings reported by the Environmental Protection Agency between the base year of 1998 and 2001. The figures were rather alarming and the Dept. found it necessary to draw the attention of the regional authorities to the long delays being experienced in the permitting processes associated with waste to energy facilities and to emphasise the need for such projects to be pressed forward.

The 2005 EPA National Waste Report (for 2004) indicated that planned measures put in place in earlier years appeared to be having a moderating effect on the amount of waste arising and the progressing of plans for new landfills also eased the position somewhat. The position regarding regions that had included thermal treatment within their portfolio of options is, at the time of completion of this report, believed to be as follows:

(1) Dublin: Proceeding through planning process for facility to handle 600Kt of MSW with installed capacity of 60MWe targeted for 2010.

* (2) Cork: Cork has a commitment to major landfill and while a 100Kt facility (8MW) has been mooted adjoining a permitted toxic waste incinerator (12MW) at Ringaskiddy this is not a specific objective of the Cork County Waste Plan resulting in a reluctance of projected PPP developers to embark on an expensive planning application. Subject to the outcome of review proceedings the toxic waste facility would be developed, with a target date of 2010.

* (3) South East Region: The Regional Waste Strategy was updated in June 2006. Managers resolved to seek a PPP for a complete bundle of services with responsibility for site selection planning and permitting process lying with the contractor. A prequalification process for contractor was expected to start early in 2007. Earliest start of site work + 2 years with perhaps 1.5 – 2 years for construction/commissioning which would suggest 2011-12 as earliest operating date. (The main uncertainty here is the 2 years for site selection/planning/appeals process, with the hope that the Critical Infrastructure legislation may assist). The facility size at 150,000t would suggest 12MWe capacity. No has site yet been selected. Great Island (Co. Wexford) is considered as a possible site purely for the purposes of this report without prejudice to more detailed investigation by others later.

(4) North East Region: Permission has been granted for a privately operated facility at Duleek, Co. Meath. Revision of the regional waste plan has led to a renewed application for an increase in capacity to 200Kt of MSW and 16MWe. The target commissioning date is 2012.

* (5) South West Region: Planning is proceeding. It is targeted to process (150-200)Kt of MSW with a commissioning date of (2012) and an electrical capacity of (12-16)MWe. It is possible that this facility might draw in material from south Galway and the south midlands (N. Tipperary, Laois) to improve economy of scale.

* (6) Connacht: This is a diffuse region with rather sparse population and planning progress has been slow.

* (7) Midlands: This is another region where progress has been slow. Some waste could be drawn off to Dublin or South West when facilities become established there and highway quality improves.

*Some doubt must attach to the viability of these projects as at the time of writing this report (2007) press statements indicate that the Minister of Environment Heritage and Local Government has indicated that local authorities would be prevented from entering present or pay contracts for waste incineration and that emphasis would be on MBT followed by composting. In addition, developers have complained of a build up in Local Authority landfill capacity, contrary to regional waste plans, with consequent undermining of prospective gate fees for waste to energy plants.

(It is understood that EPA has been considering the biological effectiveness of different MBT systems and is due to report in Autumn 2007. Pending the outcome of this report the resource indicated on Table A5.2.6 is regarded as theoretical only).

While electrical conversion efficiency in a large plant could reach a level of 0.4 and an electrical yield of 928kWhe/t of residual waste, the efficiency and yield levels must be scaled down for the smaller tonnages and appropriate plant capacities shown in the above table. If the Solid Recovered Fuel was cocombusted with other fuel in a large plant the higher electrical yield of 928kWhe/t would be appropriate for all tonnages delivered instead of the range 580 – 882kWhe/t shown above, with a corresponding increase in annual energy output.

The above table forms the basis of the best fit capital and operating cost curves used in developing the levelised costs for electricity from municipal waste treatment (Appendix 10). These curves do not take into account items such as gate fees, heat sales, renewable obligation certificates, sale of by-products, avoidance of landfill penalties, or other variable market related benefits that may arise.

If new advanced conversion technologies are to be employed in electricity production Ref. (57) advocates an electrical yield of 598kWhe/t comprised of 50% (AD Yield: 407kWhe/t + Gasification/Pyrolysis Yield : 789kWhe/t).

If waste management authorities or their service providers plan to instal MBT in any event a closer picture of the electrical costs may be obtained by deleting the ‘sorting’ capital cost element and reducing the operating cost by 50%.

This gives rise to the following tables:

Table A5.2.2

Indicative Capital and Operating Costs for Energy Recovery Plant Only

Annual Resid. Waste Capacity (kt)	50	100	200	400
Implied Plant Capacity (MWe)	3.9	9.04	20.6	47.4
Capital Cost : Power Plant €m	59	62.9	70.7	116.4
O&M Cost : Power Plant €m/yr.	2.55	3.16	4.33	6.91

The best fit cost curves over these ranges are given in Appendix 10.

The use of Advanced Conversion Technologies would imply a revised version of the above table giving Table (A5.2.3).

Table A5.2.3

Indicative Capital and Operating Costs for Advanced Energy Recovery Plant

Annual Residual Waste Capacity kt	50	100	200	40
Implied Plant Capacity (MWe)	3.26	6.53	13.06	26.32
Capital Cost : Power Plant €m	38	64.3	97.16	178.5
O&M : Power Plant €m/yr	4.03	5.5	8.06	13.28

Advanced Energy Recovery or Advanced Conversion Technology implies use of 50% Anaerobic Digestion/50% Gasification. Mean electrical yield 486.5kWhe/t.

A5.2.4 Conclusions

(1) Thermal waste to energy plants can reasonably be envisaged as coming on stream as follows if the respective waste plans are implemented.

Table A5.2.2

Potential Municipal Waste to Thermal Energy Plant Locations (All Island)

Location	Capacity	Date	Coordinates
Belfast	30MWe (43MWe)	2012 (2020)	Greater Belfast
Dublin	60MWe	2010	(320 100E, 233 600N)
Cork	12MWe	2010	(178 500E, 064 500N)
“	8MWe	2016	(“ “)
South East	12MWe	2013	(269 500E, 114 500N) **
North East	16MWe	2012	(306 500E, 271 100N)
South West	14MWe	2013	(153 900E, 154 900N)
Total	165MWe		

(**) Two adjacent locations on the River Suir estuary had been identified as potential waste to energy plant sites by commercial interests in the past. For the purposes of this study only that shown is considered.

(1) It is projected that the Belfast, Dublin and Duleek (North East) installations will be developed with full separation and recovery facilities so that the fuel is residual municipal material only. (Table A5.8.2). The Dublin (60MWe) and Duleek (21MWe) facilities to be available for Portfolios 1-6 at levelised costs of €0.06 and €0.07/kWhe respectively. The Belfast plant (43MWe) would be available for Portfolios 5, 6 at a levelised cost of €0.06/kWhe.

(2) The facilities projected for Cork (20MWe), South East (12MWe) and South West (14MWe) are considered to be somewhat more uncertain but are tentatively allocated to Portfolios 5, 6 at levelised costs estimated at €0.13, €0.11, €0.10/kWhe respectively, exclusive of gate fees, heat sale possibilities etc.

A5.3 Biomass : Landfill Gas Resource

A5.3.1 Introduction

The prospects for the landfill gas resource in the Republic were discussed recently (2004) in Reference (12). Development of the resource in Northern Ireland also forms part of the regional waste plans now being finalised there. Regional waste plans in the Republic are being updated and this together with the recent increases in fossil fuel costs may have some potential to increase the number of landfill gas developments. However the future picture will largely be determined by the EU Directive that requires phase out of the disposal of the organic waste fraction to landfills by 2012. (There is a derogation for both RoI and NI until 2016). This material is the feedstock for landfill gas production as it decays. This will mean that landfill gas production will peak some time around 2020 and will gradually decrease thereafter. These factors have been taken into account in the analysis that follows which has been informed by consultation with those directly involved in the field.

The status of the actual landfill sites is summarised on Table A5.3.1.

Table A5.3.1

Landfill Gas Production Sites

RoI	Grid Coordinates		Name	Status
County or L.A.	**E**	**N**		
Cavan	244463	307793	Corranure	Closing – 2010, circa 1MWe 2008-20
Clare	122400	180700	Ballyduff	Circa 1MWe
Cork	168000	069600	Kinsale Rd.	2 x 1MWe operational
“	182400	070300	Rossmore E. Cork	0.5MWe. Con. Cost constraint
“	210000	080000	Youghal	
“	163750	090250	Bottlehill	Pretreated waste minimal biodegradable
“	166400	114200	Ballyguyroe N.	Future
Dun Laoghaire	320700	223900	Ballyogan	2 x 1MWe operational
Dublin City	309500	238600	Dunsink	1 x 1.2MWe operational
Fingal	322330	252540	Balleally	5 x 1MWe operational
“	317606	256905	Nevitt	Permitting stage
Galway	132304	231560	Carrowbrowne	Closed 2001, - 1MWe from 2008

RoI	Grid Coordinates		Name	Status
County or L.A.	**E**	**N**		
“	185300	229200	Poolboy	- 0.5MWe, con. Cost constraint
“	171418	229674	Kilconnell E. Galway (2005)	Greenstar – 1MWe from 2010
Kerry	095052	117201	North Kerry	- 0.5MWe, con. Cost constraint
Kildare	285700	211700	Silliot Hill	1 x 1.2MWe, operational,
“	285750	211300	KTK (1999)	2 x 1.2MWe operational, 1.2MWe o/s
“	283570	202770	USK (2008)	- 1.5MWe circa 2010
“	274400	234500	Drehid	New BnM Site
“	291424	222094	Kerdiffstown	A1 Composting
“	295317	221160	Arthurstown	South Dublin (5 x 1.4MWe 2 x 1.2MWe operational)
Kilkenny	249856	160727	Dunmore	Flaring but undersized
Laois	244872	203662	Kyletelesha	Flaring but undersized
Limerick	157465	159213	Long Pavement	Old closed site
“	122678	143194	Gortadroma	- 1.8MWe
Louth	301400	285600	White River	Flaring but undersized
Mayo	104250	293525	Derrinumera	Flaring but undersized
“	123093	323702	Rathroeen	Flaring but undersized
Meath	251500	285510	Basketstown	Flaring (closed)
“	297332	267325	Knockharly	Greenstar C - 1.4MWe 2007-8 (4MWe 2012)
Monaghan	275250	325300	Scotch Corner	Flaring but undersized
Offaly	235324	220710	Derryclure	Flaring but undersized

RoI	Grid Coordinates		Name	Status
County or L.A.	E	N		
Waterford	259468	110569	Kilbarry	Flaring. Old closed site
“	224370	094752	Dungarvan	Flaring but undersized
“	259407	101315	Tramore	Flaring but undersized
Westmeath	258500	249150	Annaskinnan	Future
Wexford	298000	126500	Killurin	Flaring. Shallow site
Wicklow	319800	181500	Ballymurtagh	Flaring but undersized
“	327540	190797	Ballinagran	Greenstar - 1.5MWe 2010
Northern Ireland				
ARC21 Group	335100	378900	Dargan Rd. (Belfast)	(4MWe) operational
ARC21	311400	396200	Ballymena	0.75Mm^3 (~ .5 MWe)
ARC21	324620	368880	Mullaghglass	(~ 1 MWe)
ARC21	327600	383400	Cottonmount	(~ 2 MWe)
ARC21	325100	370100	Aughrim	Flaring (~ 2MWe)
ARC21	338300	344950	Drumnakelly	0.8Mm^3 (~ 0.5MWe)
SWAMP Group				
Newry/Mourne	313500	325500	Aughnagun	0.6MWe
Craigavon	302400	359700	Ballyfodrin	0.6MWe
Fermanagh	226400	342090	Drumnee	Small
Banbridge	305800	345250	Lisbain (Quinn)	
Cookstown	273200	376700	Magherglass	0.6MWe
Dungannon	226200	354200	Tullyvar	0.8MWe
Craigavon	305400	394300	Terryhoogan	Small
NW Group				
Ballymoney	300500	422500	Crosstagherty	Closed. Too small
Limavady	270742	415920	Drumaduff	
Coleraine	288900	438900	Craigahulliar	Operational
“	293500	411700	Kilrea	Closed. Too small

RoI	Grid Coordinates		Name	Status
County or L.A.	E	N		
“	283500	416500	Garvagh	Closed. Too small
“	281600	427500	Letterloan	Closed. Too small
“	282500	420500	Mayboy	Closed. Too small
Moyle	311100	440400	Glentaisie	Closed. Too small
“	306200	433300	Armoy	Closed. Too small
“	308400	439700	Carneatly	Closing. Too small
Derry	247900	423900	Culmore	Operational

A particular feature of the above table is the number of sites that are flaring but are considered to be too small to justify the cost of energy recovery and network connection. Site details and levelised costs are carried forward to Table A5.8.2.

It is important to note the existence of an emerging constraint on the development of landfill gas based generation in Northern Ireland. Under the UK renewable energy trading scheme the income arising would consist of a basic rate for the electricity augmented by the sale value of the corresponding Renewable Obligation Certificate (ROC). As LFG technology is seen as mature in the UK and no longer requiring developmental support it is planned to reduce the ROC element for LFG from April 2009 to only 25% of that currently prevailing. This will render new LFG plants economically unattractive to the private sector in NI from that date. Bearing in mind that it can take 6-12 months for planning permission and network connection to be obtained it leaves very little time available for development of new projects in Northern Ireland if these are to qualify under the existing trading regime. Waste authorities will still have an obligation to deal with the landfill gas.

Table A5.3.2

Landfill Gas Resource

County or LA	E	N	Name	Status	Installed Capacity	110kV Node	Levelised Cost €/kWhr
Cavan	244463	307793	Corranure	Closing – 2010, circa 1MW 2008-20	1	Shankill	€0.07
Clare	122400	180700	Ballyduff	Circa 1MW	1	Ennis	€0.08
Cork	168000	69600	Kinsale Rd.	2 x 1MW operational	2	Trabeg	€0.06
Dun Laoghaire	320700	223900	Ballyogan	2 x 1MW operational	2	Fassaroe	€0.06
Dublin City	309500	238600	Dunsink	1 x 1.2MW operational	1.2	College Park	€0.06
Fingal	322330	252540	Balleally	5 x 1MW operational	5	Glasmore	€0.06
Galway	132304	231560	Carrowbrowne	Closed 2001, - 1MW from 2008	1	Galway	€0.07
Galway	171418	229674	Kilconnell E. Galway (2005)	Greenstar – 1MW from 2010	1	Agannygal	€0.08
Kildare	285700	211700	Silliot Hill	1 x 1.2MW, operational,	1.2	Newbridge	€0.07
Kildare	285750	211300	KTK (1999)	2 x 1.2MW operational, 1.2MW o/s	2.4	Newbridge	€0.06
Kildare	283570	202770	USK (2008)	- 1.5MW circa 2010	1.5	Stratford	€0.06
Kildare	295317	221160	Arthurstown	South Dublin (5 x 1.4MW, 2 x 1.2MW operational)	9.4	Kilteel	€0.05
Limerick	122678	143194	Gortadroma	- 1.8MW	1.8	Rathkeale	€0.06
Meath	297332	267325	Knockharly	Greenstar C - 1MW 2007-8	5.4	Platin	€0.04
Wicklow	327540	190797	Ballinagran	Greenstar - 1.5MW 2010	1.5	Ballybeg 110kV Station	€0.06
ARC21	335100	378900	Dargan Rd. (Belfast)	4MW	4	POWER STATION WEST	€0.05
ARC21	324620	368880	Mullaghglass	Start up: Nov. 06	1	LISBURN MAIN	€0.09
ARC21	327600	383400	Cottonmount	Start up: Nov. 06	2	GLENGORMLEY MAIN	€0.06
ARC21	325100	370100	Aughrim		2	LISBURN MAIN	€0.06
ARC21	338300	344950	Drumnakelly	0.8Mm3	0.5	BALLYNAHINCH MAIN	€0.15

A5.3.2 Conclusions : Municipal Landfill Gas

(1) The landfill gas resource that will be available for inclusion in plant portfolios 1-6 for 2010 and 2020 is projected as 46.9MWe against a target of 68MWe leaving a projected shortfall of 21MWe. The LFG sites projected to be available for 2020 are listed in Table A5.3.2 with corresponding levelised costs ranging from €0.04 - €0.09/kWhe with one exception at €0.15/kWhe.

A5.4 Mechanical Biological Treatment of BMW

A5.4.1 Introduction

The Biodegradable Municipal Waste fraction is a subset of the Municipal solid waste stream. The total MSW figure for 2004 (Ref. 26) is 1,818,534t compared with the figure of 2,702,406t reported for 2001, a decrease of 883,872t or 32.7% over three years or 10% per annum. It is noted in Ref. (26) that 630,790t of biodegradable MSW (BMW) had been recovered in 2004 instead of going to landfill (32.6%) while 1,304,426t still went to landfill. Thus there is potential for further reduction in biodegradables.

A5.4.2 Strategic Biodegradable Municipal Waste Projections (Republic of Ireland)

Bearing the foregoing in mind, the following strategic projections for biodegradable municipal waste arising and available management methods were discussed in Ref. (34) and are summarised in Tables A5.2.1-5.

Table A5.4.1

Projected Target Municipal Biodegradable Waste Generation in RoI based on 2003 NWD Quantities and Various Influencing Factors (t)

Year	Projected Biowaste Arisings	Organic Waste (40.6%)	Wood Waste (7.6%)	Food & Garden (*) Element Recovered	Min. Bio Treatment Capacity Reqd.
2003	1,855,505	753,083	142,132		
2004	1,957,828	794,878	149,775	83,505	
2005	2,038,430	827,604	155,940		
2006	2,108,134	855,902	161,275		
2007	2,195,033	891,182	167,921		
2008	2,265,814	919,920	173,333		
2009	2,325,340	944,087	177,890		
2010	2,379,516	966,083	182,032	338,129	250kt
2011	2,380,288	966,398	182,090		
2012	2,381,127	966,737	182,157	414,546	320kt
2013	2,374,541	964,062	181,655		
2014	2,344,257	951,768	179,337		
2015	2,314,389	939,642	177,050		
2016	2,268,731	921,104	173,558	442,129	330kt
2017	2,224,037	902,958	170,139		
2018	2,180,223	885,170	166,787		
2019	2,137,273	867,732	163,501		
2020	2,095,169	850,638	159,280		476,550

Note: Organic waste includes both Household and Commercial streams : (Ref. 58)
Food + Garden Waste to composting or AD. (included in Organic Waste).

Table A5.4.2

Mandatory Landfill Targets for BMW (t)

Year 1995	Target Allowed	Max. Landfill Tonnage (t)	Diversion Reqd. (t)
1995	(Baseline) Year	1,289,911	-
July 2010	75% of 1995 level	967,433	1,412,083
July 2013	50% of " "	644,956	1,729,585
July 2016	35% of " "	451,469	1,817,262

- In general countries in EU with high landfill diversion rates utilise separate collection systems and thermal treatment to a considerable extent and anaerobic digestion to a much lesser degree. Pyrolysis and gasification are still seen as being developmental processes.

  (Composting and Biogas plants treating animal byproducts must comply with veterinary guidelines issued by DAF under EC Reg. No. 1774/2002.)

Table A5.4.3

Key BMW Diversion Targets for 2010, 2013, 2016

Year	Total BMW (t)	Recycle (t) %		Biological (t) %		Residual Requiring Treatment (t) %		Landfill (t) %	
2010	2,379,516	765,050	(32.2)	338,129	(14.2)	308,904	(13)	967,433	(40.6)
2013	2,374,541	876,849	(36.9)	414,546	(17.5)	438,190	(18.5)	644,956	(27.1)
2016	2,268,731	875,371	(38.6)	442,129	(19.5)	499,762	(22)	451,469	(19.9)

Biological treatment is mostly MBT or composting or MBT but the preferred residual treatment methods as stated in Ref. (25) were:

- Thermal treatment with energy recovery
- Mechanical Biological Treatment with energy recovery
- Mechanical Biological Treatment with fully stabilished residue going to landfill.

However the Minister (2007) has, according to press reports, signalled a shift in policy toward MBT with composting rather than thermal treatments.

The foregoing projections give an indication of the annual biodegradable municipal waste streams that provide degradable feedstock for:

- Landfill Gas Production: Landfilled BMW
- Composting or Anaerobic Digestion: BMW requiring biological treatment
- Cocombustion of wood fuel feedstock: Recovered Wood (*)
- Waste to energy thermal treatment: Residual Waste
- (* apart from chemically contaminated fraction)

These figures provide indicative envelopes of the theoretically available national biodegradable municipal waste resource for the Republic over the years to 2020. The bulk of this will arise in the vicinity of the main population centres.

Composting is very much the preferred option in the Regional Waste Plans where biological treatment is concerned and the need for adherence to specific standards is clearly understood if the large quantities of compost projected are to find acceptable end uses. Anaerobic digestion of biodegradable municipal waste is only in limited use at this stage.

Best fit projections from Table A5.4.3 of Biodegradable Residual waste requiring treatment and that treated show tonnages of 476,550 and 425,990 respectively for 2020. (Fig. A5.4.1)

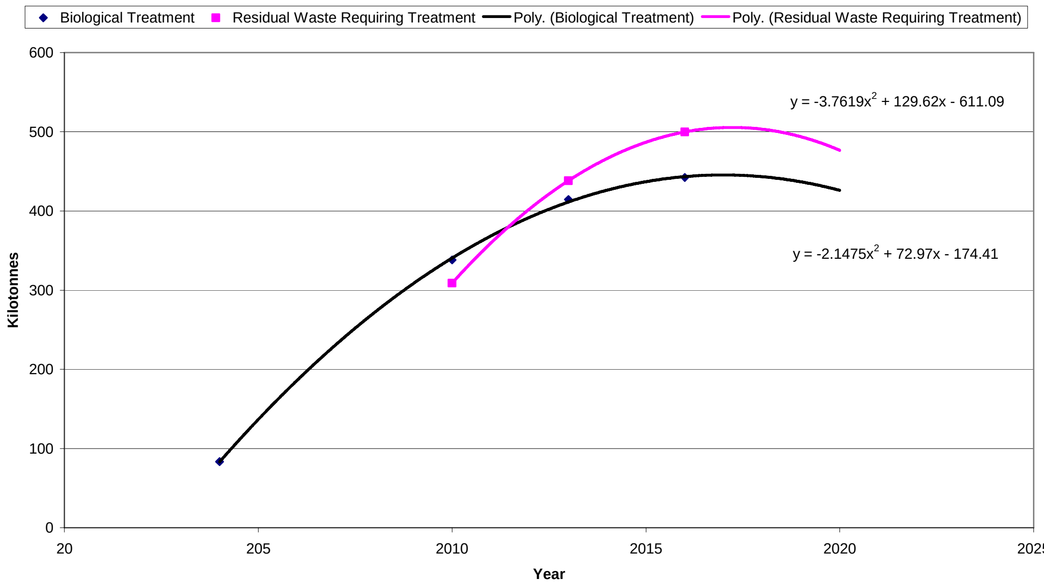
giving feedstock for a technical electrical energy resource as follows (Table A5.4.4).

Table A5.4.4

Theoretical Electrical Energy Resource Implied by BMW Strategy (2020) (RoI)

Type	Tonnage/Yr.	Treatment	Conversion Factor	Energy GWhe/Yr	Capacity MWe
Biologically Treated Waste	425,990	AD	407 kWhe/t	173.378	23.28
Wood Waste Recovery	159,280	Thermal	1166kWhe/t	169.79	22.8
Residual Waste	476,550	Thermal	714 kWhe/t	340.26	45.7

Figure A5.4.1 - Biological Municipal Waste Treatment Requirement (ROI)



These are national resource figures and give an overview of BMW position. The likelihood of their being achieved will depend on the availability of treatment and energy recovery facilities at key centres, the extent to which commercial and industrial stream is also catered for and the influence of gate fees, tariff levels etc.

The regional groupings that have been developed for waste management purposes by the local authorities were discussed in the earlier section A5.2.3 with particular reference to energy recovery facilities that are included in the portfolios under the Biomass (thermal) heading.

A5.4.3 Advanced Energy Recovery : Biodegradable Residual Wastes : Northern Ireland

The regional waste plans mentioned in A5.2.3 make provision for Machine Biological Treatment (MBT) of both residual MSW and commercial/industrial waste. They also recognise the looming problem of agricultural slurry management and the benefits of economy of scale in treatment systems.

Advanced energy recovery systems are considered to be these that produce gas using anaerobic digestion, pyrolosis or gasification of putrescible material, any one of which can form the energy recovery stage in MBT treatment. The position is summarised on Table A5.4.5 where thermal treatment (Belfast) and identified agricultural wet waste streams are also recognised. While the Local Authorities do not have responsibility for dealing with agricultural slurries there is logic to processing these at centralised plants where economy of scale and similar processing of the authorities own biodegradable waste streams can be undertaken at sites already owned by Local Authorities even if the plants were operated by others.

This allows the projected electrical energy resource from biodegradable municipal, commercial and a segment of the wet agricultural waste resource to be summarised in extent and location. The agricultural waste stream is discussed further in Section A5.6.

Table A5.4.5

Northern Ireland : Projected Power Capacity of Local Authority Waste Streams (excluding LFG)

Area	Type of Waste		Treatment Process	Reqd. Capacity kt	Units	Potential Locations
	MSW	1	MBT	60-70	2	Derry (Lisnahally); Coleraine (Letterloan), Ballymoney (Crosstagherty)
	"	2	AD	-	-	-
	"	3	Thermal	-	-	Not utilised
NW	C + 1	4	MBT	8	1	No location (combine with MSW in (1)
		5	AD	7	1	No location (combine with Agri in (8)
		6	Thermal	20	1	Belfast (included in Belfast thermal in (24))
	Agri	7	MBT	-	-	Not utilised
	"	8	AD	60 – 150	2	Derry/Strabane/Limavady/Lisahally and Coleraine/Ballymoney (Letterloan or Crosstagherty)
	"	9	Thermal			Not utilised
	MSW	10	MBT	160-170	3	2 @ 75kt Newry/Armagh (Aughnagun or Croreagh) or Omagh (Tullyvar) + 1 @ 30kt

SWAMP						Fermanagh (Drumnee)
	“	11	AD	30-35	1-2	No sites Prorated to sites in (10)
	“	12	Thermal	-	-	Not utilised
	C + 1	13	MBT	40	2-3	No sites Prorated to sites in (10)
	“	14	AD	9	2-3	No sites Prorated to sites in (10)
	“	15	Thermal	28	-	To Belfast (See ARC 21, No. 21)
	AGRI	16	MBT	-	-	-
		17	AD	60 – 150	2-3	Cookstown (Magheraglass), Dungannon (Tullyvar), Armagh, (Terryhoogan) or Newry (Aughnagun or Croreagh)
Private		18	Thermal	300	1	(Poultry litter) Glenavy
Arc21	MSW	19	MBT	325	3	North (Cottonmount)?, Central (Mullaghglass) South, (Lisbain)?
		20	AD	-	-	Not utilised
		21	Ther.	370	1	Belfast
	C + 1	22	MBT	26	1	No location. Included in MSW MBT (17000t to North, Central, South (19)
		23	AD	25	1	No location. Included in MSW MBT (17000t to North, Central, South (19)
		24	Ther.	79		Included in Belfast Thermal (21)
	Agri	25	MBT	-	-	No specific provision
		26	AD	-	-	No specific provision
		27	Ther.	-	-	No specific provision

Table A5.4.6

Sumary of Waste to Energy Projections for Northern Ireland

Area	Waste Types	Process	Possible Location	Energy Output MWhe/Yr.	Capacity MWe
NW	MSW + C & 1	MBT/AD	Derry	29711	4
	MSW + C & 1	MBT/AD	Letterloan	29711	4
	WET Agri.	AD	Drumaduff	12450	0.57
	WET Agri.	AD	Cross Tagherty	12450	0.57
SWAMP	MSW + C & 1	MBT/AD	Aughnagun	44542	6
	MSW + C & 1	MBT/AD	Tullyvar	44542	6
	MSW + C & 1	MBT/AD	Drumnee	17550	2.4
	Wet Agri.	AD	Magheraglass	8300	0.375
	Wet Agri.	AD	Aughnagun	8300	0.375
	Wet Agri.	AD	Tullyvar	8300	0.375
Private	Ag. Chicken Lit.	Thermal	Glenavy		24MWe
Arc 21	MSW + C & 1	MBT/AD	Cottonmount	50875	6.4
	“	“	Mullaghglass	50875	6.4
	“	“	Aughrim	50875	6.4
	“	Thermal	Belfast	320178	43
				Total	**110.865MWe**

A5.4.4 Conclusions

(1) This analysis allows the projected electrical energy resource from biodegradable municipal, commercial and a segment of the wet agricultural waste resource to be summarised in extent and location. (The agricultural waste stream is discussed in detail in Section A5.6).

(2) It is concluded that MBT/AD when applied to the processing of the biological component of MSW and C+I waste in Northern Ireland will give rise to a capacity of 41.6MWe (Table A5.4.6) at levelised costs ranging from €0.25 – 0.46/kWhe (Table A5.6.5).

(3) In the Republic the emphasis in local authority treatment plans for biodegradable municipal waste has been to focus on direct composting in preference to digestion with energy recovery followed by composting of digestate.

A5.5 Anaerobic Digestion : Municipal Waste Water

A5.5.1 Introduction : Republic of Ireland

The following urban projects are operational at present:

Table A5.5.1

Electricity from Sewage Gas

Location	Installed Capacity
Dublin City	4MWe
Kildare (Osberstown)	160kWe
Clonmel	120kWe
Tralee	55kWe
Total	4.335MWe

It is understood that there is little prospect of significant electricity generation at other urban locations as technologies other than anaerobic digestion are planned.

As these plants are already operational, projections of levelised costs do not arise.

A5.5.2 Anaerobic Digestion : Municipal Waste Water : Northern Ireland

Sludge from the main Belfast waste water plant (Operated by Water Service) is incinerated without electricity production. Sludge from Derry is applied to short rotation coppice at Culmore.

A5.5.3 Conclusion

(1) The present capacity as shown on Table A5.5.1 is rounded to 4.5MWe and is available in Portfolios 1-6. As it is already connected to the network the question of projected levelised costs does not arise.

A5.6 Biomass : Agricultural Waste to Energy : Anaerobic Digestion

A5.6.1 Introduction

The production of methane from the anaerobic digestion of agricultural slurries and municipal waste water has long been recognised as a means of energy recovery from waste but it has not heretofore reached a significant scale in electricity production terms in Ireland. Even a development such as the Dublin Bay Project which treats the sewage from the city of Dublin and its environs has, as noted above, only an electrical capacity of 4MWe which is rather less than its own electrical demand.

A number of uncertainties arise in using the tabulated animal numbers for the period to 2020 but in general an overall reduction is expected due to the downward pressures on livestock that are expected to arise from:

- Reform of agricultural policy since 2000 (the next agricultural census is not due until 2010)
- The direction to be taken by the Common Agricultural Policy post 2013 when the present arrangements are due to be replaced.
- The effect of the currently stalled Doha round of World Trade Negotiations

Ref. (44) addressed the potential role of centralised anaerobic digestion (CAD) primarily as an aid to managing discharges from agricultural and other waste water sources in sensitive catchment areas with energy production as a secondary output. It was largely based on the situation prevailing pre 2001 and included a county by county analysis of potentially suitable areas for CAD plant location using a weighting system of points that took account of

- Local authority interest level and track record
- Available biowastes arising
- Number of potential sites within county
- Sensitive catchments
- Availability of spread lands
- Farm sizes

While the national production levels of agricultural wastes are large these are so dispersed that only where they are concentrated by the presence of agrifood plants can anaerobic digestion for electrical production show much promise. In other cases it is more cost effective to consider use of the biogas for local heating and drying etc. without the complication of electricity production. The position may change as more biodegradable municipal waste is diverted from landfill although the target destination for most of this material appears to be compost under existing plans.

A5.6.2 Agricultural Anaerobic Digestion – Northern Europe

While well established for many years in the treatment of municipal waste water and industrial sludges, anaerobic digestion with energy recovery for farm wastes has been a more problematic process in terms of scale, reliable technology and economics. To place the technology in context the experiences of its development and application in two other north European countries (Ref. 51) are summarised in the following section. It is seen that numerous factors, both inside and outside the technology itself influenced its development and application. In general there has been a shift away from focussing upon its energy value per se to viewing it as part of a suite of waste and environmental management measures that depend on an appropriately 'joined up' political, regulatory, and economic framework for successful utilisation.

A5.6.3 Denmark, Holland, Ireland : Contrasts in Agricultural AD Experience

Despite over thirty years of research and development effort (with significant public investment) associated with both farm scale and centralised anaerobic digestion of agricultural waste in both Netherlands and Denmark it is only in recent years that the promise shown by the technology has begun to bear fruit.

Work in both countries was triggered by energy costs following the 1973 oil crisis but followed different paths subject to rather different political and regulatory regimes with the latter being subsumed into wider EU regime in more recent years. Considerable public funds were expended and a key difference appears to have centered on the research feed back and continuity maintained in Denmark.

While earlier activities focussed on energy recovery, with somewhat indifferent results, they later become part of a more integrated effort to manage waste, in particular nutrient distribution, reduce fertiliser intake and greenhouse gas emissions while conserving energy via an existing network of CHP facilities.

Even in Denmark the economics of centralised facilities were marginal and there was significant dependence on gate fees, grants and soft loans. Codigestion with other waste streams has been an essential feature as has a supportive regulatory regime.

Changes in agriculture and liberalisation of the electricity market have had conflicting impacts but have introduced further uncertainty which has hit investment. Thus attention again switched to the smaller scale projects which are more akin to landfill gas installations than power stations.

In the Irish context, the period under review showed little development on the scale attempted in Denmark or Holland. A few small privately owned installations and those at research establishments demonstrated the technology while the pharmaceutical and food processing industries adopted anaerobic digestion for dealing with their own particular waste streams and discharge conditions.

Attempts to establish central AD plants to cater for regional or subregional farm and related wastes have failed so far. Given this climate and, from the County Planning perspective, an expectation (Ref. 50) that initial projects should only be at demonstration scale it is difficult to see significant additional development under this heading by 2020. In that context aggregate developments of 1.0MW and 3.5MW respectively in Northern Ireland and the Republic are suggested for consideration.

This is equivalent to evaluating the accessible resource as being limited to (1.5%) of the Theoretical resource in each case and this is the conversion factor used in the following Accessible resource tables, by analogy with the Danish and Dutch figures of 3.5% and 0.1% respectively.

Without changes in attitude at planning and waste management levels it is difficult to see event this level being achieved in the time period to 2020. It is important to distinguish between the waste and nutrient management aspects of such projects and their energy value.

A5.6.4 Anaerobic Digestion : Agriwastes : Republic of Ireland

A5.6.4.1 Introduction

In estimating this resource the following conventions were used:

- Livestock numbers taken from Census 2000 (Ref. 37)
- Cattle assumed housed for 4 months of year
- Slurry recovery factors assumed: Cattle 0.1, Pigs 0.1, Poultry and Food 0.75 (Ref. 24)
- Energy per tonne of respective wastes as per Table A5.6.1
- The resource was tabulated on a county basis for this report.

Table A5.6.1

Indicative Unit Agricultural Biogas Energy Yield

Livestock Type	No. of Stock per t of waste per day	Biogas Yield M^3/t	Energy/M^3 MJ/M^3	Mean Energy MJ/t	Mean Thermal Energy kWht/t
Cattle	10-40	25	23-25 (24)	(25) (24) : 600	167
Pigs	250-300	26	21-25 (23)	(26) (23) : 598	166
Laying Poultry	8000-9000	90-150	23-27 (25)	(120 (25) : 3000	
Broiler Poultry	10000-15000	50-100	21-23 (22)	(75) (22) :1650	
Poultry Weighted Average				1866	518
Food Proc.	-	46	21-25 (23)	(46) (23) : 1058	294

The thermal energy value of gas produced from the respective slurries are estimated to be as per Table A5.6.1. The slurry recovery factors play a crucial role in estimating the size of the Practicable Resource and may of course be the subject of debate at different locations. In this case values equivalent to those of Ref. (24) have been taken for 2020. (Cattle 0.1, Pigs 0.1, Poultry 0.75, Food Waste 0.75). These are multiplied by the gas collection factor G = 0.8 to allow for loss of gas from stored slurry prior to and after digestion.

An EPA sponsored investigation (Ref. 44) made a detailed assessment of the potential for centralised anaerobic digestion in the treatment of agriculture and food wastes in the Republic.

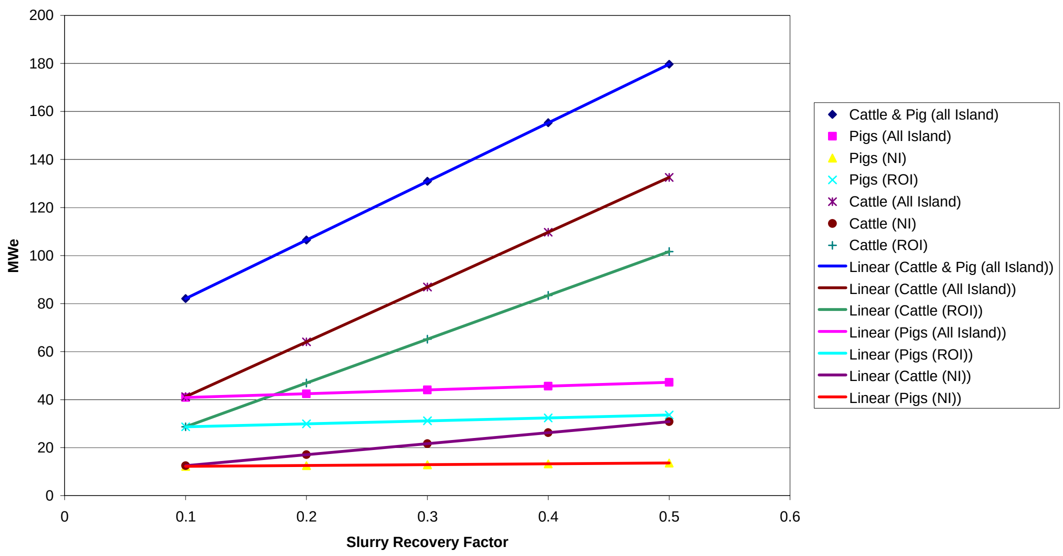
In a later report Ref. (49) EPA staff also argued that in the national interest strong financial support should be made available for centralised anaerobic digestion as a methane/CO_2 emission management tool rather than as a power generation mechanism.

While the sites listed in Ref. (44) may be prime points of development at some stage in the future the numerous regulatory hurdles (Ref. 44) that face such projects suggest that some greater economy of scale must be discussed in this section than 0.5 – 1MWe.

Sensitivity analysis (Fig. 5.6.1) shows that increasing the percentage of cattle or pig slurry treated produces a linear increase in total Practicable energy and power capacity. These result in total practicable capacity levels of 102MWe (RoI) and 31MWe (NI), totalling 133MWe (all island) for a 50% level of cattle slurry recovery (SRF = 0.5). In the case of pig slurry a similar level of recovery would give total practicable capacity levels of 33.4MWe (RoI) and 13.6MWe (NI) totalling 47.7MWe (all island). In both cases the poultry and food processing waste collection levels are kept at 75% (SRF = 0.75). For the purposes of this study conservative SRF levels for cattle and pig slurry have been kept at 0.1 as in Ref. (24).

Thus notwithstanding the size of the practicable resource implied by Fig. 5.6.1 it has been decided at this stage to focus on the commercially driven proposals of Section A5.6.3 one of which (Vale) appears to incorporate the Cork North project envisaged by Ref. (44).

Figure A5.6.1 - Sensitivity of Practicable Power Capacity (MWe) to Cattle and Pig Slurry Recovery (Food, Poultry Recovery 0.75)



A5.6.5 Anaerobic Digestion : Agriwastes : Northern Ireland

A5.6.5.1 Introduction

While the scope of the regional waste plans prepared by NW, SWAMP and ARC21 is confined to municipal waste streams nevertheless there has been recognition of the reality of agriwastes in some plans.

At one point consideration had been given to the implementation of a large number of small scale anaerobic digestion schemes to deal with agricultural and agrifood wastes in Northern Ireland. It was noted (DARD 2004) that 9.7m tonnes/year of manure was produced from housed livestock in Northern Ireland (88% cattle, 7% pigs, 5% poultry) having the potential to fuel 91 centralised anaerobic digestion plants each utilising 100 000 t/year and that each scheme might have an electrical capacity of about 1MWe. It was projected that by 2012 six such schemes might support 7MWe of electrical capacity rising to a total of 14MWe by 2020. However it now appears that cost considerations have ruled this out.

Unfortunately a projected pilot project at Fivemiletown (2 x 1MWe) failed to materialise although it is understood that local difficulties relating to the way the project was perceived may have contributed to this.

The current most likely pilot project under consideration is one at Cookstown.

It is also intended that a small anaerobic digester will be installed at Hillsboro agricultural research station to provide combined heat and power for government offices. The performance of this plant will be monitored by DARD scientists and it may be that following successful operation there may be a greater take up of anaerobic digestion for electrical production in Northern Ireland. However it is probably unlikely that more than circa 5MWe installed capacity will be achieved by 2020.

A5.6.5.2 Potential Agricultural AD Resource (Northern Ireland)

As noted above DARD scientists examined the potential of centralised anaerobic digestion (CAD) as a means of dealing with the wastes produced by housed livestock while recovering energy and managing the nutrients produced. The power potential from 91 CAD plants accepting 100,000t/yr. of manures per plant was estimated at 73MWe and 60MWt heat. For sustainability however there must be sufficient land available to utilise all of the crop nutrients contained in the resultant digestate. In addition to farm animal wastes, centralised anaerobic digestion plants can accept non toxic industrial organic wastes particularly from food processing and other agro industrial residues which can significantly enhance biogas yields.

Input of municipal waste (sewage) to these plants was not considered as the Farm Quality Assurance Scheme did not permit the application of sewage sludge on participating farms. Digestate storage at the CAD plant can assist farmers in meeting at least part of their slurry storage obligations. Strict management protocols are necessary in relation to CAD plants to ensure that all down stream risks of contamination by pathogens are minimised.

It was noted that each plant would also require an associated land area for the spreading of digestate. This area would vary depending on soil type, utilisation (arable, silage or grazing land) and existing NPK levels. The limiting factor for Northern Ireland was reported as being the P_20_5 dosage level per Ha which could lead to excess levels of P locally although not on a province wide basis. Nutrient partitioning can alleviate this problem, at increased cost.

Table A5.6.2

Sequence used in Deirving Accessible Resource from Theoretical Energy Level of Waste (NI)

Technical Energy Resource	=	Theoretical Energy x (η = 0.30)
Technical Power Capacity	=	(Tech. Energy GWhe x 1000) ÷ (8,760 x 0.85)
	=	Tech. Energy GWhe x 0.1343
Practicable Energy Resource	=	Tech. Energy Resource x G = 0.8 x SRF
		(G = Gas Collection Factor) (SRF = Slurry Recovery Factor)
Slurry Recovery Factor (SRF)	=	(0.1) Cattle; (0.1) Pigs; (0.75) Poultry; (0.75) Food Waste
Practicable Power Resource	=	Pract. Energy Resource x 1000 ÷ (8,760) (0.85)
Accessible Energy Resource	=	**16.87GWhe**
Accessible Power Resource	=	**2.265MWe**

Table A5.6.3

Wet Agri-Food Waste AD Resource Levels

Republic	**Cattle**	**Pigs**	**Poultry**	**Food**	**Total**
Slurry t/yr *	33,906,838	2,285,425	438,337	518,485	-
Theor. Energy GWht	5,662.44	381.66	227.03	153.99	6,425.12
Technical Energy GWhe					1,927.5
Technical Power MWe					258.85
Practicable Energy GWhe					213.61
Practicable Power MWe					28.686
Accessible Energy GWhe					6.42
Accessible Power MWe					0.86
Northern Ireland					
Slurry t/yr *	8,497,902	668,444	520,685	150,000	-
Theor. Energy GWht	1,420.74	110.92	269.67	40.41	1,841.74
Technical Energy GWhe					553.62
Technical Power MWe					74.35
Practicable Energy GWhe					93.236
Practicable Power MWe					12.52
Accessible Energy GWhe					16.87
Accessible Power MWe					2.265

* Cattle assumed housed for 4 months (winter)

A5.8.4 Anaerobic Digestion : Agricultural/Municipal Biogas

As summarised in the above table (Republic of Ireland and Northern Ireland respectively) the **practicable** power capacity levels under the assumptions made were estimated at circa 29MWe and 13MWe respectively or 42MWe distributed over the whole island. The realistically **accessible** resource is likely to be much less than this unless driven by other forces e.g. Nitrates Directive or the need to manage industrial byproducts. The two projects (47MWe) identified in Section A5.6.3 are nominated for inclusion in Portfolios 1-6 from 2010 onwards giving a total capacity of 91MWe. These are based on the inclusion of other animal wastes e.g. meat and bonemeal material from rendering etc. in addition to slurries. This would leave shortfalls of 115MWe (Portfolio 5), 178MWe (Portfolio 6) under this heading for 2020.

In Northern Ireland within this total of 91MWe, there are good prospects for the development of several small centralised CHP anaerobic digestion plants but each of these are likely to be less than 1MWe in capacity totalling 2.265MWe. These are included with the Local Authority projections of Table A5.5.3 on the basis that they might, if desired, be colocated on local authority owned sites.

A5.6.6 Selection of a Projected Accessible Resource Level

Based on the earlier comparative discussion relating to Danish and Dutch experience (Section A5.6.2) it is suggested that a credible level of accessible energy resource for development by 2020 would be circa 3% of the Northern Ireland Theoretical resource and, as derived in Table A5.6.4, this equates to about 0.33MWe. The compact land area of Northern Ireland suggests that this could be located at a single site or, at most, a few locations.

It was noted however in Section A5.5.3 that the Northern Ireland area waste management groupings NW and SWAMP recognised the need to include agricultural wet wastes in their forward plans for the period to 2020. Tonnages arising, type of treatment, and possible locations for treatment sites are shown on Table A5.5.2. (It is emphasised that the inclusion of such sites in this report should in no way be interpreted as limiting the ability of these waste management groupings to nominate such other sites as they may deem appropriate for the provision of future waste management services).

The tonnages of agricultural slurry being targeted in these waste plans suggest that electrical energy recovery capacity of 2.265MWe could be provided as detailed in Table A5.5.3. This would be additional to that provided for dealing with the Municipal Waste.

As noted earlier 3.5% of the theoretically available manure tonnage (and its corresponding energy resource) is treated by anaerobic digestion in Denmark and may reasonably be regarded as the demonstrable level of accessible resource there. The total wet animal manure tonnages for all Ireland (dominated by cattle manure) are summarised in Table (A5.6.9).

At these levels the total tonnage of manure waste for Ireland is less than for Holland but similar to that for Denmark. It would appear to be unduly optimistic to assume that a figure much higher than the Danish level of anaerobic digestion could be achieved from a standing start in Ireland by 2020, given the weaknesses in the planning system referred to in Section A5.6.2.4 above, however it is useful to examine the implications of achieving accessible resource levels somewhat below the Danish benchmark. These are given in Table (A.5.6.4 based on calculations made for this Appendix.

Table A5.6.4

Potential Accessible Energy and Power Resource as a function of Anaerobic Digestion Levels

Republic of Ireland

% Manure Waste Digested		0.5	1.0	1.5	2	**3**	4

*	Theoretical Energy Resource	GWht	33.13	66.25	99.38	132.5	**198.75**	2.65
*	Technical Energy Resource (η=30%)	GWhe	9.59	19.27	28.9	38.54	**57.68**	77.08
*	Technical Power Capacity	MWe	1.3	2.59	3.89	5.18	**7.77**	10.36
*	Practicable Energy Resource (G=0.8)	GWhe	1.07	2.14	3.21	4.28	**6.42**	8.56
*	Practicable Power Capacity	MWe	0.14	0.287	0.43	0.574	**0.861**	1.148
	Accessible Energy Resource	GWhe	1.07	2.14	3.21	4.28	**6.42**	8.56
	Accessible Power Capacity	MWe	0.14	0.287	0.43	0.574	**0.861**	1.148
Northern Ireland								
% Manure Waste Digested			0.5	1.0	1.5	2	**3**	4
*	Theoretical Energy Resource	GWht	9.22	18.45	27.67	36.09	**55.35**	73.8
*	Technical Energy Resource (η=30%)	GWhe	2.768	5.536	8.3	11.07	**16.6**	22.14
*	Technical Power Capacity	MWe	0.372	0.743	1.115	1.486	**2.229**	2.97
*	Practicable Energy Resource (G=0.8)	GWhe	0.465	0.93	1.395	1.86	**2.79**	3.72
*	Practicable Power Capacity	MWe	0.56	0.12	0.167	0.22	**0.335**	0.446
	Accessible Energy Resource	GWhe	0.465	0.93	1.395	1.86	**2.79**	3.72
	Accessible Power Capacity	MWe	0.056	0.12	0.167	0.22	**0.335**	0.446

* Scale of resource limited by % considered to be realistically accessible for digestion.

η Conversion efficiency from theoretical to technical resource (η = 0.3 at this scale)

G Gas collection factor = 0.8. Allows for loss of gas in pre and post AD stages)

Being constrained by the credible scale that can be assigned to the accessible resource based on Dutch and Danish experience, the figures in the above table represent only a fraction of the theoretical, technical and practicable resources that are otherwise available. Assuming that an accessible resource level of 3.0% of theoretical is achievable for 2020, the projected installed capacity would be only 0.87MW_e (RoI) and 0.335MW_e (NI), spread over several sites.

However it will have already been noted from Tables A5.4.5 and 6 that the municipal waste authority groups NW and SWAMP in Northern Ireland are recognising the need for treatment of agricultural slurries equivalent to capacities of 1.14MWe and 1.125MWe respectively in their areas (total 2.265MWe). This represents 3% of that theoretically available for Northern Ireland as a whole and would place it on a par with Denmark in terms of AD treatment of agricultural waste. This figure is therefore taken as representing an accessible target for Northern Ireland for 2020 in preference to the figures in the above table A5.6.4.

For the Republic the accessible capacity is retained at 0.86MWe by 2020 (12% of that technically available from 3% of the manure resource) in the absence of a more coordinated overall waste management policy and the larger distances involved.

(The addition of biodegradable municipal waste on a gate fee basis could alter the scale and economics of some such plants although separation of liquid and solid digestate with subsequent composting of the latter would then appear to be necessary to minimise difficulties in utilising land spreading for digestate disposal.

Most local authorities in the Republic appear to plan on using direct composting rather than digestion (with thermal processing of other residues) to deal with their biodegradable municipal waste in any event).

A5.6.7 Planned Commercial Anaerobic Digestion Schemes – Republic of Ireland : Agriculture

The following developments proposed by the commercial sector have been identified:

(a) Vale Project, Ballard Co. Cork (187700E, 106600N), Projected Capacity 32MWe, (including meat and bonemeal input) Targetted commissioning date 2009. (Notwithstanding the fact that this project has been rejected upon Planning Appeal, ESBI has been requested to retain it in the Portfolio for planning purposes by the Steering Group and it is understood that the promoter is considering a different site.)

(b) Rose Green Project, Co. Tipperary (213500E, 132500N). Projected capacity 15MWe, Commissioning Date 2010. (Currently in Planning Application).

(c) Silver Hill Project, Co. Monaghan, 0.15MWe, Commisioned 2006

These are carried forward to Table A5.6.5 with their respective levelised costs.

A5.6.8 Anaerobic Digestion : Agricultural/Municipal Biogas Resource

Table A5.6.5

Accessible Anaerobic Digestion from Agricultural/Municipal Waste (Portfolios 1-6)

Name	County or LA	Technology	Fuel	E	N	110kV Node	Installed Capacity	Levelised Cost €/kWh
Drumaduff	NW	Anaerobic Digestion	Agri Waste	270742	415920	Limavady Main	0.57	€0.09
Cross Tagherty	NW	Anaerobic Digestion	Agri Waste	300500	422500	Coleraine Main	0.57	€0.10
Aughnagan	SWAMP	Anaerobic Digestion	Agri Waste	313500	325500	Newry Main	0.375	€0.11
Tullyvar	SWAMP	Anaerobic Digestion	Agri Waste	226200	354200	Enniskillen Main	0.375	€0.11
Magheraglass	SWAMP	Anaerobic Digestion	Agri Waste	273200	376700	Dungannon Main	0.375	€0.12
Mullaghglass	ARC21	MBT/AD	Mun. Solid Waste + Commercial/Industrial	324620	368880	Lisburn Main	6.4	€0.25
Cottonmount	ARC21	MBT/AD	Mun. Solid Waste + Commercial/Industrial	327600	383400	Glengormley Main	6.4	€0.25
Aughrim	ARC21	MBT/AD	Mun. Solid Waste + Commercial/Industrial	323400	371000	Finaghy Main	6.4	€0.25
Aughnagan	SWAMP	MBT/AD	Mun. Solid Waste + Commercial/Industrial	313500	325500	Newry Main	6	€0.28
Tullyvar	SWAMP	MBT/AD	Mun. Solid Waste + Commercial/Industrial	226200	354200	Enniskillen Main	6	€0.28
Derry	NW	MBT/AD	Mun. Solid Waste + Commercial/Industrial	247500	421500		4	€0.33
Letterloan	NW	MBT/AD	Mun. Solid Waste + Commercial/Industrial	281600	427500	Coleraine Main	4	€0.33
Drumnee	SWAMP	MBT/AD	Mun. Solid Waste + Commercial/Industrial	226400	342090	Enniskillen Main	2.4	€0.46
Vale Project, Ballard*	Cork	Anaerobic Digestion	Agri Waste	187700	106600	Barrymore	32	€0.14
Rose Green Project **	Tipperary	Anaerobic Digestion	Agri Waste	213500	132500	Cahir	15	€0.15

* *(Note: Although the above Vale Project in Co. Cork failed at Planning Appeal, ESBI has been instructed to maintain a project of this size and location in Portfolios 1-6 for energy planning purposes on the basis that an aggregate of smaller projects or a similar single project in the Cork region could reasonably be projected to come on stream by 2020).*

** *Portfolios 5,6 only*

Table 5.6.6

Accessible All Island Anaerobic Digestion from Agricultural/ Municipal Industrial Waste

Name	Technology	Raw Material	Projected Capacity MWe	Portfolio	€/kWhe
Drumaduff	AD	Ag. Slurry	0.57	1-4	0.09
Crosstagherty	AD	"	0.57	"	0.10
Aughnagan	AD	"	0.375	"	0.11
Tullyvar	AD	"	0.375	"	0.11
Magheraglass	AD	"	0.375	"	0.12
Mullaghglass	MET/AD	BMW/C+1	6.4	"	0.25
Cottonmount	"	"	6.4	"	0.25
Aughrim	"	"	6.4	"	0.25
Aughnagan	"	"	6	"	0.28
Tullyvar	"	"	6	"	0.28
Derry	"	"	4	"	0.33
Letterloan	"	"	4	"	0.33
Drumnee	"	"	2.4	"	0.46
Vale	AD	Ag. Waste	32	"	0.14
Rosegreen	AD	"	15	5-6	0.15
Total			91		

Note that Waste Authorities could opt to recover energy from BMW/C+1 residues as RDF or similar instead of Anaerobic Digestion as shown here.

A5.6.9 Conclusions : Wet Agri food Industry Biogas

(1) The projected all island municipal, agricultural and industrial waste biogas resources (excluding LFG and sewage) are summarised on Table A5.6.6 showing total capacity (91MWe), relevant portfolios and levelised costs ranging from €0.10 to €0.46.

(2) In the Republic the planned commercial projects (Ballard and Rose Green) dominate projected input from the wet agri waste sector (and a further facility rated at 8MWe to process meat/bone meal has been proposed at Nobber, Co. Meath during finalisation of this report). It is probable therefore that the

commercial rather than public or small scale private sector will drive energy recovery via anaerobic digestion in the south.

A5.7Biomass : Dry Agricultural Waste : Thermal Treatment

A5.7.1 Republic of Ireland

A5.7.1.1 Poultry Litter

In recent years the poultry population has been approximately steady at 13.9 million birds in the Republic and 16.8 million in Northern Ireland at any one time (Ref. 11). Broilers and breeding fowl give rise to litter (moisture content 35-46%) whereas layers and ducks give rise to slurry (moisture content – 90%). (Ref. 11).

In the Republic poultry litter production is concentrated as follows Monaghan 64%, Limerick 18%, Cork 7%, Waterford 9% and totals about 140,000t/yr. The principal disposal options are:

(1) 42-70% used as mushroom compost feedstock

(2) 30-58% used in land spreading which has been increasing due to a decline in the mushroom industry.

Approximately 24-40,000t of litter would be available for energy production at a value close to its transport cost of €18-20/t. The potential power capacity of a plant utilising the entire practicable poultry litter resource was estimated at 2.1 – 3.5MWe. This suggests that although a very small plant might be located in the Monaghan area, partly fuelled by material from Northern Ireland, better economy of scale would be achieved by cocombustion with other fuel or transport to a larger plant in Northern Ireland. (An attempt to obtain planning permission in Monaghan for a 22MWe capacity plant, fuelled annually by up to 150,000t of poultry litter, including material from Northern Ireland and 4800t of wood waste, failed to obtain Planning Permission in recent years).

5.7.1.2 Straw

Ref. (11) notes that the total grain production for the Republic over the decade 1993-2003 averaged 2 million tonnes, utilising 285,000Ha of cultivation, of which circa 70% was in Leinster and 15% in Cork, giving rise to a theoretical availability of 1.3 million tonnes of straw. The straw yield per Ha varies with crop type and a higher average is obtained in the Republic than in Northern Ireland. Seasonality of straw production is very significant (mid July – mid September each year) as this implies storage costs. The estimated total figure for 2000 was 1.45Mt composed of 53% barley, 40% wheat, 7% oats. The different types have different end uses.

Based on the annual fluctuation of grain production, the Theoretical Straw Resource was estimated to be in the range 1.2Mt – 1.46Mt/yr. for the Republic or 1.3Mt – 1.6Mt/yr on an all island basis (87% RoI, 13% NI).

Straw production in Ireland is low relative to the number of cattle in the country compared with elsewhere in Europe. It is estimated that 70-80% of straw is used as animal bedding. A balance of circa 140kt of wheaten straw might arise over bedding requirements but about 100-120kt of wheaten straw would find its way into mushroom compost while circa 30kt might be stored or ploughed back in.

It is projected that both cattle numbers and straw production will fall gently (circa 1% year) at least to 2012, if not beyond, due to CAP reform and other factors and that an accessible resource of 10% of the average theoretical resource can be taken. This amounts to circa 133kt per annum. This would equate to a total installed capacity of circa 17MWe (or 12.5MWe + 25MWt if used in CHP configuration). Either of these options would require a plant designed to deal with the particular levels of corrosive elements (chlorides) that occur in straw. In the

Republic the distribution of the straw resource is concentrated in South and Mid Leinster and East Cork. Because of the competing specialist markets for barley and oaten straw the plants must target wheaten straw, which is only grown on a rotational basis. The low density of straw results in a significant transport cost element.

For the purposes of the All Island Grid Study it is considered that there is little attraction for commercial interests in the development and operation of a standalone straw burning electrical plant and that cocombustion as a minor fuel in a plant utilising other primary solid fuels is a more likely possibility. This is always subject to the caveat that there will be a reluctance to use the fuel due to its potentially deletiorious effects on boiler and heat exchanger surfaces.

It is unlikely therefore that an identifiable installed capacity of straw burning plant will arise in the context of this study but that if used will be submerged as part of the fuel feed to other, most likely fluidised bed, plants.

5.7.1.3 Spent Mushroom Compost

Mushroom compost consists of chicken litter, wheaten straw, water and gypsum, processed and spawned with mushroom mycelium and bagged for distribution to growers. Following collection of the final mushroom crop, the spent compost is a highly variable quality material with a moisture content around 65% and a rather poor energy value, 3.2MJ/Kg at that moisture content. Dry SMC has a calorific value of ~ 12.5MJ/kg. Thus it ranks below wood chips, peat, poultry litter, and straw in calorific value. While there has been consolidation in the mushroom industry in recent years the output has remained fairly constant and Ref. (11) estimated that the Theoretical SMC resource in Ireland at 290kt. Most of this was disposed of by land spreading and for Co. Monaghan the acceptable limit has been reached resulting in material from that county being disposed of elsewhere. Using the ratio of SMC concentration/pasture area for Monaghan as a permissible limit for land spreading in any county Ref. (11) identified the excess material arising as 92,500t (all island) or 76,000t (RoI).

The bulk of the SMC arising in Ireland occurs in Co. Monaghan and adjoining counties and the unsuccessful planning application for a thermal power plant there had envisaged consumption of 200kt of SMC via cocombustion with 150kt of poultry litter and 4.8kt of wood waste. The cross border nature of the mushroom business dictates that any energy production plant(s) should be located in Monaghan, Cavan or Armagh with an emphasis on minimising transport costs and recognising the reducing opportunities for land spreading due to regulatory pressures.

This led (Ref. 11) to identification of an accessible resource within a 45km transport radius of 78,600t (whole island) or 62,000t (RoI) per annum. Due to the poor combustion characteristics of the material and its low calorific value this latter would only equate on its own to an electrical capacity of 1.85MWe. (Unfortunately its straw content renders it a difficult material for anaerobic digestion). Thus it appears that cocombustion with locally produced chicken litter as was proposed in the Monaghan plant was the right option. It may be that this will be revived in the projected Northern Ireland chicken litter combustion plant (A5.7.3) if this proceeds as planned. At this point no generation capacity is ascribed to the SMC resource for the purposes of this study.

5.7.1.4 Utilisation of Vegetable Oil, Tallow, Meat & Bone Meal

For the purposes of this report Recovered Vegetable Oil (RVO) and tallow are considered to be more suitable as feedstocks for premium products such as road biofuels rather than as fuel for power generation. While meat and bone meal can be utilised successfully in particular types of power plant there is a concern that the additional regulatory and operational load (effectively treating these plants as incinerators) is not justified by the return involved.

A5.7.2 Northern Ireland

A5.7.2.1 Poultry Litter

Examination of Table A5.6.7 shows that a substantial tonnage of poultry waste (chicken litter) arises annually. Its nitrogen content would require typically 21,000 Ha for disposal by land spreading at an unsustainable cost. (Ref. 39). Serious consideration is therefore being given to the construction of a 24MWe chicken litter fuelled plant to deal with this problem, for commissioning about 2009.

It may be noted that some poultry litter fuelled plants in Great Britain (Eye and Glanford) were successfully adapted to the use of meat and bonemeal fuelling.

It is projected that the plant may be located at Glenfarm near Glenavy for which tentative coordinates of (314500E, 373500N) are assigned.

A somewhat similar proposal located in Co. Monaghan failed to secure planning permission in recent years.

The project is carried forward, with levelised cost of €0.07/kWhe to Table A5.8.3 and A5.8.5 as part of portfolios 5, 6.

A5.7.3 Costs

Based on the curves of Fig. A10.5 (Appendix 10) the levelised cost for a plant of 24MWe scale would be €0.07/kWhe exclusive of gate fees etc.

A5.7.4 Conclusion

(1) The most likely project of this kind to proceed during the immediate future is a projected chicken litter fuelled installation of 24MWe capacity in Northern Ireland. This can be nominated for inclusion in all portfolios for 2020.

A5.8 Biomass : CHP Wood Waste to Energy (Saw Mills) : Thermal Treatment

A number of saw mills are projected to have combined wood drying and electricity generation plants operational in 2020, fuelled by residual wood material available as mill byproducts. The small scale and variable seasonal loads reduce efficiency of these plants even where operated in CHP mode. The plants are detailed in Table A5.8.1 and carried forward to Table A5.9.1 as part of the thermal waste resource of Portfolios 1-6.

Table A5.8.1

Wood Waste to Energy CHP Plants (All Island)

Name	Installed Capacity MWe	Coordinates		Fuel	110kV Node	Levelised Cost €/kWhe
		X	Y			
Munster Joinery	2.7	115590	104240	Mill Residues	Glenlara	0.07
Balcas Joinery	3	223440	344220	Mill Residues	Enniskillen Main	0.08
Murray Joinery	2	178560	252660	Mill Residues	Athlone	0.11
Graingers Saw Mills	2.7	136000	054500	Mill Residues	Bandon	0.09
Total	10.4					

Those levelised costs appear high as they have been based on charging the full cost of wood fuel as there are now alternative markets for most of the former wood wastes (e.g. pellets and chips).

A5.9 Biomass Summarised Waste to Energy (Thermal)

A5.9.1 Introduction

This summary gathers the scale locations and levelised cost ranges applicable to the projected waste fuelled thermal plants that were identified on a whole island basis during the study.

Table A5.9.1

Summarised All Island Thermal Waste to Energy Resource 2020

Plant	Rating MWe	Fuel	Portfolio	Levelised Cost €/kWhe
Dublin	60	Municipal Residue	1-6	0.06
North East	21	Municipal Residue	1-6	0.07
Munster	2.7	Saw mill Residue CHP	1-6	0.07
Balcas	3	Saw mill Residue CHP	1-6	0.08
Murray	2	Saw mill Residue CHP	1-6	0.11
Grainger	2.7	Saw mill Residue CHP	1-6	0.09
Subtotal	91.4			
Belfast	43	Municipal Residue	5-6	0.06
Cork	20	Mun. & Ind. Residue	5-6	0.13
South East	12	Municipal Residue	5-6	0.11
South West	14	Municipal Residue	5-6	0.10
Glenavy	24	Agri. Chick Litter	5-6	0.07
Sub-Total	113		5-6	
Total	204.4			

Table A5.9.2

Projected Waste Biomass Fuelled Thermal Plants (2020)

Name	Installed Capacity MWe	X	Y	Fuel	110kV Node	Levelised Cost € per kWh
Belfast	43	334700	377200	Municipal Waste	Power Station West	€0.06
Dublin	60	320100	233600	Municipal Waste	Ringsend	€0.05
Cork	20	178500	64500	Municipal Waste	Haulbowline	€0.13
South East	12	269500	114500	Municipal Waste	Mungret	€0.11
North East Duleek	21	306500	271100	Municipal Waste	Platin	€0.07

Name	Installed Capacity MWe	X	Y	Fuel	110kV Node	Levelised Cost € per kWh
South West	14	153900	154900	Municipal Waste	Waterford	€0.10
Munster Joinery CHP	5	115590	104240	Wood Biomass	Glenlara	€0.07
Balcas Joinery CHP	3	223440	344220	Wood Biomass	ENNISKILLEN MAIN	€0.08
Murray Joinery CHP	2	178560	252660	Wood Biomass	Athlone	€0.11
Graingers Sawmills CHP	2.7	136000	54500	Wood Biomass	Bandon	€0.09
Glenavy (GlenFarm)	24	314500	373500	Chicken Litter	LISBURN MAIN	€0.07

A5.9.2 Conclusions : Biomass (Thermal)

(1) The projected all island municipal waste, sawmill residue and chicken litter resource currently scheduled for energy recovery via thermal treatment are summarised on Table A5.9.1 showing relevant portfolios and levelised costs ranging from €0.05 to €0.13/kWhe. Total capacity amounts to 204.4MWe.

A5.9.3 Recommendations

(1) It is recommended that the respective capacities and resource cost curves arising should be carried forward as part of the dispatchable capacity element of Portfolios 1-6, with identification of shortfalls arising.

Appendix 6

Biomass : Forestry and Short Rotation Coppice

A6.1 Introduction

There have been a number of recent reports (5, 6, 7, 14, 15, 20, 23, 24) discussing the potential of these resources for energy production both in the Republic and Northern Ireland. It has been pointed out that as far as the forestry resource is concerned whatever fuel may be available within the timeframe of this report (2020) has already been planted. The reverse is true where short rotation coppice (SRC) is concerned where growers and users are still ‘feeling their way’ and where the likely final direction to be taken is by no means certain.

Based on a review of the most recent reports and interviews with key personnel the issues involved are discussed in the following sections, which deal with Forestry and SRC respectively.

A6.2 Managing the Forest Resource within Climate Change Strategy

In examining the extent of the forestry resource it is important to note the expectations that arise in the revision of the Republic’s National Climate Change Strategy in respect of forestry.

Table 1.1 of that report (Ref. 33) shows that afforestation is projected to account for an annual average sequestration of 2.08Mt in a total of 7.95Mt CO_2 during the years 2008-12. This is the largest contributor to sequestration (accounting for 26%) apart from decoupling of the Common Agricultural Policy. It should be noted that current or replacement afforestation takes several years before it has any significant effect in this regard.

Since 1990, 244000 Ha have been planted averaging 15000Ha/year with 1500Ha deforested over the same period. However rates of afforestation have slowed to circa 10,000Ha/year. At the end of 2006 the national estate was 710,000Ha, covering about 10% of the country compared to an EU average of 35%. A full review of future forest strategy was due for completion in 2006.

The long term nature of utilisation of the forest resource must always be borne in mind when considering its potential for electricity production in 2020.

In 1996 the Government issued a strategic plan for forestry development with the objectives of planting 25,000Ha annually to 2000 and 20,000Ha annually thereafter to 2030 so that a productive forest area of 1.2MHa would be available. In fact rates decreased from 1997 onward to about 15,000Ha by 2001 despite what were considered to be attractive support measures and a report (Ref. 45) was commissioned to establish the reasons for the decline in interest among farmers/land owners who were the group targeted with achievement of the policy.

It found that there were both socio economic and institutional reasons for the decline and in its recommendations sought to retrieve the position by focussing attention on:

- Influencing future changes in agricultural policy such as to promote forestry on land that is unsuited to farming.
- Ensuring that maximum stability attends forest policy particularly in relation to agriculture.

- Targeting in particular
    - These farmers already owning plantations
    - Part time farmers
    - The 37,000 farmers owning 490,000Ha considered difficult to farm and having low livestock stocking rates
    - Farmers without identifiable successors or encountering labour shortages etc.
    - Farmers in the South East Region
- Indexation of forestry premiums at a level that would reflect competing land use value and the long term nature of the commitment. (Premiums were payable at a fixed rate for 20 years).

It was found that a number of environmental constraints (Sustainable Forest Management, Water Quality, Acid Sensitivity, Biodiversity, Landscape, Archaeology, Sensitive Areas, Physical constraints, Nitrates Directive, Extensification, Rural Environmental Protection Scheme, EIS Obligations) had impacts on the level of afforestation, including delays due to the number of bodies involved and collectively deleted in excess of 1.85 million Ha of the total land resource. An emphasis on broad leaved species rather than conifers can lead to a reduced annual output for energy production purposes and increases cost.

It was also noted that at the time of the report a number of farmers were waiting for various policy, market and other issues to resolve themselves before reaching decisions on future commitment to afforestation.

While some of these issues may ease or be actively addressed in the years to 2020, it is necessary to bear in mind their likely damping effect on the production of forest wood fuel for electricity production. In addition diversion of material to wood chip/pellet production for institutional and domestic heating will have an impact.

It is now a requirement of the current REPS programme that areas suitable for forestry are identified on participating farms and this will continue during 2007-13 and REPS participants who wish to do so will be fully accommodated in respect of afforestation. It was projected that 55,000 farmers (40% of total) would be participating in REPS by end of 2006.

A commercial bioheat grant scheme is in hands to replace oil with a targeted 600GWht of wood fuel heating per annum.

In Northern Ireland ‘First Steps towards Sustainability’ Ref. (1) noted that forestry policy was now a matter of international importance and that the NI Government is committed through the “Forestry Strategy – A Strategy for Sustainability and Growth” to ensuring that all forests are managed to national standards and to see the area of forests increased. Funding for afforestation will be increased under the Northern Ireland Rural Development Regulation Plan with an initial target of adding 1500Ha by 2008. The Plan is subject to review in 2013. The existing Woodland grant scheme will be revised to increase the rate of new planting where certain types of forestry seem particularly desirable. Some conifer plantations on ancient woodland sites are to be restored to native woodland in the interest of education and biodiversity. Under (Ref. 1) it is a key target to increase Northern Ireland’s forested area by at least 500Ha per annum.

In light of the above a number of factors need to be borne in mind

- The existing forest resource has to be managed sustainably but, as noted earlier, there is some conflict between the needs of bulk supply for power generation, wood based industries, heating and possible future biofuel production and environmental demands for biodiversity, mixing of broadleaved and conifer species, de-emphasising of conifers and small farm based plantations as all these increase the costs of production.
- Existing wood based industries will probably continue to have first call on materials produced unless the costs of production in Ireland drives these industries overseas.
- Forestry being a long term commitment is rather less attractive to many farmers than would be short rotation coppice or biofuel production. While both forestry and SRC target essentially the same market where energy is concerned, they should probably be seen as complementary to each other. However certain types of SRC (e.g. Miscanthus or other grasses) may not be suitable for particular boilers due to their mineral burden and the combustion temperature attained.
- Problems of scale and infrastructure affect forest biomass production in Ireland and direct transfer of methods, equipment and costs applicable overseas is not necessarily appropriate here.
- Importation of biomass in bulk from overseas is not facilitated by the location of the three modern peat plants in the Midlands. While Moneypoint and Kilroot have marine facilities to handle imported fuels, significant modifications could be required to handle biomass imported in smaller vessels than the bulk carriers used for coal delivery.
- The primary biomass fuels available for electricity production within the timescale of this report are seen to be chipped Forest/Wood Industry residues and SRC.

A6.3 Competition for the Wood Biomass Resource

It is accepted by Refs. 59, 62 that the state forest output is now essentially in balance with user needs, indeed Ref. (59) notes that it has reached a plateau that will be sustained for several years going forward (2015?) and that imports from Scotland have become necessary to meet needs. Apart from replanting cleared areas, new planting by state organisations (Coillte and NIFS) has dwindled to virtually nothing while it has been Government policy for some years that new plantations should be primarily developed by farmers with state assistance and Fig. A.6.4 shows that for 1995 the target of 25,000Ha of new planting was achievable. Consequently forward projections for additional forecast sourced energy purposes must depend on

- Thinnings from private plantations
- Harvesting of private plantations
- Possible residues from both Coillte and Private Plantings

The output from NIFS, currently 400,000t/yr, is taken as feeding into the existing 'balanced' whole island market. Concerns have been expressed is that if private owners do not have a market into which to sell thinnings then this stage of husbandry will be neglected to the detriment of both present and future output. It is of course necessary to assess the stability of the future fuel supply process given that

- The Governments afforestation planting targets are not currently being met (Fig. A.6.1, 2) (Refs. 45, 64 give reasons for this)
- The heat sector requirements are projected to rise by 387,286t/yr by 2010 and to 3.95 – 5.35Mt/yr by 2020 depending on whether medium (50%) moisture content millwood coproduct or higher (60%) moisture content pulp wood is used for chipping etc.

COFORD projections beyond 2020 show that it is necessary to secure planting levels of around 10,000Ha/yr together with appropriate thinning to ensure a sustainable energy level of 4-5Tj/yr well into the century. The figure for 2020 being (based on existing plantings) 2,597,000GJ or 455,614t of pulpwood. But the increased heating projections alone appear to require possibly 5.35Mt/yr of pulpwood by that date.

It is generally agreed that it is most cost effective if heating fuel is dealt with on a local basis but using service providers with sufficient economy of scale to keep collection, processing and distribution costs down while adhering to necessary chip or pellet quality standards. Thus there appears to be a shortfall of circa 4.9mt/yr to be made up if the wood heating projections are to be met. Undoubtedly there is scope for recovery of further forest residues (brash, tops and branches) leaving pine needles behind as nutrition but this material is more difficult and expensive to extract, is less amenable to mechanisation and perhaps more appropriate to the small scale operator working to satisfy local market needs. Ref. (62) quotes EPA as having identified a potential 0.5Mt of wood residue as being available each year for energy recovery but it is admitted that transportation and processing costs would diminish this potential.

A further problem is that if the long awaited 'second generation' biofuel production processes involving lingocellulose materials become viable by 2020 or shortly thereafter they will represent another possibly attractive avenue for private forest materials and residues. Thus there appears to be a prospective competition arising between the heat market and electricity market among others by 2020. It is unlikely that this can be resolved at a stroke by CHP developments as the relevant power stations with the possible exception of Kilroot are in relatively sparsely populated areas. It also places emphasis on the possible role of short rotation coppice in making up the projected shortfall. This is discussed in Section A6.6 below.

A6.4 Bioenergy from Wood Residues

Traditionally the power industry utilises large volumes of low cost commodity fuel such as peat, coal or heavy fuel oil (power station fuel oil is a residual oil with the consistency of tar) to produce a premium product in the form of electricity. Until well after the discovery of natural gas there was resistance to using this premium fuel for electricity production. Thus the daily tonnages of solid fuel used in the production of electricity are relatively large compared to the tonnage of wood material that has been available.

It is projected (Ref. 24) that the energy value of wood residues is likely to rise from 4.9PJ/yr. (2001) through 9PJ/yr. (2010) to 17PJ/yr. (2020) above that already being utilised as a source of practical bioenergy in Ireland. Thus in 2020 wood residues were projected to make up about 50% of all the biowaste converted to energy, being approximately equal to energy crops, MSW organics, LFG, net organic residues and dry agricultural residuals combined.

The most notable barrier perceived at the time was stated to be lack of a clear and visible Government policy followed by the economic reality that the then relative prices of biomass fuels and fossil fuels made the former uncompetitive. The lack of clear policy was seen as the reason for numerous regulatory issues which also served to hamper development. It was recognised that the supply of energy crops could not be put in place until demand became strong and reliable and that growth in supply would need to be stimulated so that farmers became willing to plant before a fully developed demand market had arrived. In fairness efforts have since been made to redress some of these problems.

Priority pathways identified included cofiring in electricity generation and industrial wood residue CHP. It was envisaged that by 2010 bioenergy could contribute 22PJ to primary energy requirement including an additional installed capacity of 140MWe for electricity generation with an output of 822GWhe per annum and an additional 210GWht of renewable heat (leading to a CO_2 abatement of 820kt per annum). This however included all biomass sources e.g. anaerobic digestion gases, LFG, chicken litter etc.

Wood energy may be derived from (1) direct biomass (trees); (2) indirect biomass (process hyproducts and residues); (3) post consumer recovered wood.

In relation to direct biomass it is projected that the supply of pulpwood is set to grow steadily based on forest thinnings from increased planting in the last two decades. Thinning typically takes place about 16 years after planting. Whole tree chipping is considered the most efficient process option at industrial level. A further potential direct biomass resource is forest residues. In both cases however there are reasons why successful Continental practice in harvesting these resources cannot be automatically applied in Ireland with success.

Indirect biomass includes sawmill "wastes" such as sawdust, bark, woodchip, slabwood and offcuts from primary and secondary processing. Sawmill owners however point out that this can be of the order of 50% of incoming material for which they have had to pay the full market price and that it represents a significant cost to them. Where possible sawmills utilise this material for active secondary markets (even export) or to generate heat for drying etc. and in a couple of cases for generating electricity on a small scale. This material is a particular source of wood pellets for heating as the pellet bonding utilises the conifer resin in the sawdust.

Post consumer recovered waste wood is usually well dried out and has an energy value of about twice that of fresh biomass making it a good constituent for pellets where a consistent high density, high energy, low ash product is desired.

Energy crops for heat and electricity production have become focussed on short rotation coppice willow and Miscanthus. It must be stated that while there are some reservations about both of these crops it is only now that growing on a sufficient scale is beginning to take place can these practical issues be resolved in Ireland. As stated elsewhere in this report there is a choice becoming available to farmers as to whether their crops should be grown for use as transport biofuel or for heat/electricity purposes (or indeed whether they should revert to cereal production where prices are rising due to the amount diverted to biofuel production internationally).

With regard to biomass resource data in general Ref. (24) notes that such estimates of the practical resource as could be made were not absolute and depended on:

- Relative prices between conventional and bioenergy
- Competing uses of biomass (board manufacture etc.)
- Practical challenges and costs of extraction, collection, collation, storage
- Geographical limitations on transportation from source to usage point
- Likely growth of energy crop planting in response to agricultural policy and supports
- Likely energy conversion pathways for each resource

Three scenarios were projected for 2010 and 2020. The sources for the data in each scenario are given in Annex K to the above referenced report.

For the medium scenario, these results may be summarised below (Table A6.1) and provide an indication of the theoretical and practicable resource growth envisioned over the period to 2010 and 2020. The figures are slightly below those projected in the reference given as it is believed that the calorific values quoted there are somewhat on the high side.

Table A6.1

Medium Scenario Projection of Forest Biomass Resource to 2020

			2001			2010			2020		
	Moisture Content %	Calorific Value GJ/t	Theoretical Resource Mt	Practicable Resource Mt	Practicable Energy PJ	Theoretical Resource Mt	Practicable Resource Mt	Practicable Energy PJ	Theoretical Resource Mt	Practicable Resource Mt	Practicable Energy PJ
Practicable Rec. Wood Availability %		25%	-	-	-	60%	-	-	85%	-	-
Annual Growth '01-'10 %		-	-	-	-	3.6%	-	-	-	-	-
Annual Growth '10-'20 %		-	-	-	-	-	-	-	3.3%	-	-
Pulpwood	60%	5.7	1.14	0.17	0.969	1.41	0.41	2.337	2.23	1.05	5.98
Sawmill	50%	7.7	0.98	0.09	0.693	1.27	0.21	1.617	1.42	0.36	2.772
Forest	50%	7.7	1.07	0.23	1.771	1.34	0.29	2.233	1.65	0.35	2.698
Recycled C+D	23%	12.8	0.13	0.03	0.384	0.18	0.11	1.408	0.24	0.21	2.688
Total Pract Resource			**3.32**	**0.52**	**3.817**	**4.2**	**1.02**	**7.595**	**5.54**	**1.97**	**14.138**

* CV @ 0% moisture content : 18.0 GJ/t

** C+D: Construction + demolition wood waste

A preliminary global estimate of the projected residual wood availability to 2020 for utilisation in the heat and electricity markets shows that the practicable energy resource figures for all four wood material streams total 7.59PJ(2106GWh_t) and 14.138PJ(3922GWh_t) for 2010 and 2020 respectively. At an efficiency of 0.38 and a capacity factor of 0.85 these energy outputs would imply potential installed electrical capacities of 107MW_e (2010) and 200MW_e (2020).

The report computed the following wood sourced power outputs for the years 2010 and 2020 under the three scenarios.

Table A6.2

Potential Wood Fuelled Power Capacities

Scenario	2010	2020
Low MWe	4.27	9.61 (25.35)
Medium MWe	21.37	48.06 (126.79)
High MWe	32.05	67.64 (182.45)

Figures in brackets represent gross power capacity if used in CHP configuration which is not likely to be widespread in 2010.

These figures are not particularly high in an all island context and even the high wood fuel scenario of 2020 (67.6MW_e) does not meet the co-firing demand of 103.7MW_e for the Midland stations, ignoring the needs of Moneypoint, Kilroot and possibly Tawnaghmore, Ref. (65). The medium scenario meets only 46% of the requirement of Portfolios 1 to 4.

However the more recent COFORD projections for pulpwood when expressed in terms of power capacity show that with an annual private planting level of 10,000Ha up to 90MWe could be sustained (Fig. A6.6) although realistic transport constraints etc. would reduce this.

A6.5 Cofiring

Largely because of the cost penalties associated with CO_2 production the three peat fired power plants at Edenderry (117.6MWe), Lough Ree (91MWe) and West Offaly (137MWe), which are fitted with fluidised bed boilers, are potential economic users of wood biomass possibly to the extent of 30% substitution for peat. While the planning permissions for these stations stipulated rather short permitted lives (15 years) consistent with the terms of their public service obligations, fuel purchase and power purchase agreements, it is understood that adequate peat resources exist for longer periods. However towards the end of the technical lives of the ESB stations there may be a shortfall in locally available peat resources. Cofiring with woody materials would of course extend the life of the peat resources.

However it has been noted (24) that cofiring the Edenderry (now owned by Bord na Mona) plant alone to 30% substitution would consume 680GWh of fuel annually (27.6% of that available nationally under the medium scenario. On a pro rata basis this would imply that the ESB plants would consume 53.5% of the national wood fuel availability, totalling 81% of the medium scenario fuel availability if one considers the three plants). As the catchment areas of the three plants will converge the wood industry would be under severe pressure to provide this fuel, even allowing for the use of the BNM rail network, bearing in mind that economic transport distances are suggested as being limited to about 50km radius and that much of the forest resource is in the northwest and south of the island. If in addition the Tawnaghmore plant (mixed coal, peat, biomass fuel) comes on line it will also draw biomass (up to 400,400t/yr) from the Midland and Western pool.

These plants are rather poorly placed to facilitate use of more competitively priced imported biomass where coastal plants like Kilroot have already demonstrated a useful level of coal substitution during tests, despite the need for a degree of double handling. The role of complementary energy crops must then be considered.

A6.6 Energy Crops (SRC)

Short rotation coppicing involves planting a fast growing woody plant such as willow or rough grass like miscanthus or canary grass where the plantation is cut back at the base to increase yield and is then harvested annually for about 15-20 years. Ref. (24) notes that in the Republic 4.4 million hectares of land are used for agriculture, 80% of which is grassland (3.5MHa) with 11% (0.48MHa) in rough grazing and 9% (0.399MHa) in crop production. It projected that, due to CAP reform, reduction in herd size and cereal production could free up 132,000Ha and 11,600Ha respectively while remaining outside the strictures of Appendix 4.

Research conducted in Northern Ireland has shown that SRC willow holds more promise there than does miscanthus due to local climatic conditions whereas trials of miscanthus in the South (based on UK experience) have shown promise. SRC willow is a crop that is also amenable to climate conditions in the South.

Industry sources in Northern Ireland emphasise that the real economic breakthrough for SRC growers came when the growing crop found a role in the treatment of urban sewage sludge, with a corresponding gate fee. Similar operations are under way in the South on a small scale. There are limits to the possibilities in this direction.

However, the regular production of the large quantities of biomass fuel that would be necessary for significant electricity production requires the development of reliable large scale professional operations where the growing, harvesting and processing of the crop takes place with the economy of scale and reliability necessary to guarantee participants an acceptable return commensurate with the risks involved in departing from traditional land uses. The fact that markets can open up for energy crops in the areas of heat, electricity and biofuels (when the processing of lignocellulose materials for biofuels becomes commercially viable) may enhance the prospect of woody energy crops being produced in the first instance but also increases the level of competition among users.

Ref. (24) projected that a practicable SRC resource of 5000Ha might be available in 2010 increasing at a rate of 1000Ha/year to reach 15000Ha by 2020. This would imply that the initial willow or miscanthus planting (5000Ha) took place in 2007. In fact about 900Ha of miscanthus is reported to have been planted in the Republic in this year and it is shown below that this rate must be doubled if SRC is to play a significant role in cofiring in combination with residual wood fuel (and peat).

Table A6.3

Land Areas Required for Cofiring with SRC Willow Alone

Station	Edenderry	Lough Ree	West Offaly	Totals
Capacity MWe	117.6	91.0	137.0	344.0
30% Capacity MWe	35.28	27.3	41.1	103.63
Fresh SRC Moisture %	55-60	55-60	55-60	-
SRC Calorific Value MWht/t	1.73	1.73	1.73	-
Average SRC Yield t/Ha/Yr *	22	22	22	-
Energy Yield MWht/Ha	38.06	38.06	38.06	-
Capacity Factor CF	0.85	0.85	0.85	-
Net Plant Efficiency η	0.38	0.38	0.38	-
Required SRC Area Ha	18,163	14,055	21,160	53,379
SRC Derived Energy GWhe/Yr	262.69	203.28	306.03	772

Area of SRC Willow Required: (Capacity x 8760 x CF) ÷ (η x 1.73 x 22)

Table A6.3 shows that a total of 53,000Ha would be required if SRC alone was to provide the full 30% cofiring fuel desired for the peat fired stations in Portfolios 1-6. If the medium scenario for potential wood fuel supply for cofiring of Table A6.2 was obtained and the balance made up from SRC the capacity thus fuelled would amount to 55.7MWe implying an area under SRC of 28,666Ha in 2020, using the conventions of Table A6.3. This is double the planting rate envisaged in Ref. (24) and also utilises the higher average yield of 22 wet tonnes/Ha projected by Ref. (14). The area is however only about 20% of that projected earlier as coming free due to CAP reform. The additional areas required for SRC or forestry implied by Portfolios 5 and 6 may be more problematic where home produced material is concerned.

- Portfolio 5 (requires 67MWe additional to Portfolios 1-4)
  - Kilroot firing 32.16MWe (Wood Biomass)
  - Tawnaghmore 34MWe (Wood Biomass)
  - Sub-total capacity 66MWe
  - SRC Area subtotal 39,979Ha
  - Total (Portfolios 1-5) 87,358Ha
- Portfolio 6 (additional to Portfolio 5) requires
  - Moneypoint Gasification or cofiring 107.2MWe
  - Sub-total 107.2MWe
  - SRC Area Subtotal 52,431Ha
- Total (Portfolios 1-6) 139,789Ha

* (Average SRC willow yield 22t/Ha/Yr derived from 66 Fresh tonnes/Ha per 3-year crop interval with 1 additional year allowed to first crop)

At Kilroot and Moneypoint marine access, berthing and fuel handling facilities appear to be reasonably well placed to import wood biomass although not without modification to existing coal handling facilities and permitting.

A6.7 Moneypoint

Ref. (14) suggested biomass gasification as a suitable technology for use at Moneypoint. Further consideration suggests that this may not be an appropriate technique although CFB gasifiers can accept material with moisture content as high as 60% (typical pulpwood level) two disadvantages arise

(1) The current largest size of unit has only been demonstrated at a scale of circa 20MWe, equivalent, only one fifth that required to meet the 107MWe rating required at Moneypoint for Portfolio 6

(2) The gasifier has to be close coupled to its companion boiler which it feeds with a high volume of high temperature gas of relatively low calorific value. The layout of the plant at Moneypoint, particularly now that Flue Gas Desulphurisation plant has been installed, makes close coupling physically difficult to envisage. While scale up of CFB gasifiers will probably take place over the coming years it cannot be regarded as a proven technology upon which the most important base load plant in the country should depend. A necessary feature of such refractory lined gasifiers is their slow warm up time (circa 16 hours) needed to protect the lining hence limiting their use to base load operations.

The merits of the gasification system was that it should cause minimal interference with the existing station and its biomass fuels should pose minimal threat to existing boiler system integrity, including its ash product which is used in the cement industry. These appear to be neutralised by the points made above, consequently the analysis made in this report has focussed more on the possibility of adopting the existing fuelling system to cater for a small percentage of biomass fuel being added. This starts at the jetty where an alternative facility capable of accepting smaller vessels than the 50-400kt bulk carriers for which the existing jetty and unloading system were designed. There are numerous safety issues involved in the offloading, conveying, storage and milling of wood chip material all of which would require a level of detailed engineering analysis and design which is outside the scope of this report but a preliminary estimate of the capital cost involved has been made to allow estimation of an order of magnitude incremental levelised cost. No modification of the existing plant could be contemplated until the new flue gas desulphurisation systems have bedded down and achieved their specified performance guarantees. A full assessment of the vulnerability of the catalyst inventory to new fuel inputs would then be a necessary part of evaluating the possible future role of biomass at Moneypoint.

(3) Miscanthus and grass type fuels will be unsuitable for Moneypoint due to their introduction of particular elements such as sodium and chlorine which are detrimental at the temperatures reached in operation.

A6.8 Kilroot

Kilroot has successfully cocombusted palm oil and oil cake pellets using imported material and a temporary conveying system. A planned programme of tests utilising home produced wood pellets from Messrs Balcas in Enniskillen did not however take place. It is understood that the fuel mills at Kilroot are not ideal for dealing with fibrous biomass material and that because of this cocombustion level would be limited to 10% of fuel feed. Importation also involved double handling in that the material was offloaded in Belfast and stored offsite before being fired in the boiler.

Again an estimate has been made without detailed engineering analysis for the capital cost element of the system enhancement that might be required to allow long term of cocombustion imported woody biomass at Kilroot in line with the requirements of Portfolios 5 and 6, reaching 32MWe. It is understood that Kilroot is being fitted with flue gas desulphurisation in the future and it is likely that similar reservations as those expressed in relation to the introduction of biomass to Moneypoint will apply for some time.

Thus it can be seen that while the forest biomass resource on its own would be hard pressed to meet the demands for cofiring in existing power stations, conceptually these could be adequately met if the forest based material was supplemented by short rotation coppice, provided that this could be produced at acceptable price and rate of planting, together with imports to coastal stations.

A6.9 Tawnaghmore

Tawnaghmore is at this point a projected multifuel powerstation (peat, coal, wood) to be located in the North West near Kilalla. It would be reasonably placed in relation to forest resources although material from the area is already being railed to Waterford for the pulpmill industry. If coal is to be imported the implication is that it would come by sea in which case the importation of biomass may be also facilitated. There are residual peat deposits in the North Mayo area but added transport costs would be a factor and permitting of additional peat fired generation may encounter difficulties.

The supporting information lodged appears to show that wood biomass could be drawn from all counties west of the Shannon, some of which would also be a natural source of supply to the Midland peat stations particularly West Offaly and Lough Ree. The location appears rather distant from areas most suitable for large scale short rotation coppice but at a 30% cocombustion level a dedicated plantation area of 15,445Ha would be implied here using the conventions of Table A6.3. As this plant has possible high (400kt/yr) or low (250kt/yr) modes of wood consumption, the higher has been taken. This implies a biomass fuelled output of 253.5GWhe and a capacity of 34MWe at CF = 0.85.

A6.10 Wood Based Heat Sector

An important factor to be considered is the projected development of biomass input to the all island heat market going forward. Both North and South, initiatives have been put in place to facilitate the installation of pellet and chip fuelled appliances at domestic and institutional levels and take up has been strong. There is a corresponding development on the supply side with players seeking to establish an early position based on imports in the absence of sufficient home produced material. Forward projections focus on substitution of fossil heating fuels by biomass, targeting a 5% level by 2010 and 12% by 2020 Ref. (63). Based on the data of Ref. (62) this suggests, allowing for the same rate of growth in the heating market between 2010 and 2020 as is projected between 2004 and 2010, (75.3ktoe = 347,973t/yr) that the biomass requirement for 2020 will have reached 3,351,627t/yr (at 50% moisture content) coming simultaneously with the projected cocombustion projections it gives some feel for the level of imports that may be necessary.

A6.11 Incremental Levelised Costs – Cocombustion

The extent of cocombustion and the projected range of incremental levelised cost estimated for each portfolio are as follows. (At the request of the Steering Group these were made on a marginal or incremental basis covering the capital cost of the additional plant only rather than including apportioned costs of the existing installations at Moneypoint, Kilroot. As the Tawnaghmore plant is designed to burn biomass from the start apportioned costs are used here).

Table A6.4

Projected Wood/SRC Biomass Cofiring Plants 2020

Name	Biomass Capacity MWe	X	Y	Fuel	110kV Node	Levelised Cost € per kWh
Edenderry	35.25	263100	229800	Wood Biomass	Edenderry Power Station	0.09
Lough Ree	27.3	201615	270971	Wood Biomass	Lough Ree Power Station	0.11
West Offaly Power	41.1	197160	225143	Wood Biomass	West Offaly Power Station	0.10
Tawnaghmore	34	120400	327900	Wood Biomass	Tawnaghmore 110kV Station	0.08
Kilroot	32.16	342900	390000	Wood Biomass	Kilroot Power Station	0.081
Moneypoint	107.2	103506	151550	Wood Biomass	Moneypoint Power Station	0.076

Table A6.5

Projected Cocombustion Levels and Levelised Costs (Wood Biomass)

Plant	Biomass Fuelled Capacity MWe	Applicable Portfolio	Levelised Cost €/kWhe
Edenderry	35.25	1-6	0.09
Lough Ree	27.3	1-6	0.11
West Offaly	41.1	1-6	0.10
Kilroot	32.16	5, 6	0.081
Tawnaghmore	34	5, 6	0.08
Moneypoint	107.2	6	0.076

A6.12 Conclusions

(1) The static forest resource has a critical role to play in the National Climate Change Strategy. Governments North and South remain committed to increasing the level of this resource but the demands of biodiversity and other environmental criteria, see Appendix 4, militate somewhat against these objectives.

(2) Reasonable projections of the forest based biomass resource (pulpwood, sawmill waste, forest residues and recycled construction/demolition wood waste) show that it could only support a power capacity by 2020 with a medium scenario level of 48MW_e.

(3) Short Rotation Coppice could however augment this range considerably, supporting 56MW_e by 2020 if planted initially on 5000Ha expanding to 28,700Ha by 2020. This would meet the co-firing requirements of Portfolios 1-4.

(4) Alternatively utilising Short Rotation Coppice alone the following areas would typically be required:

Portfolios 1-4 : 129MWe : 53,378Ha

Portfolio 5 : 196MWe : 87,358Ha

Portfolio 6 : 277MWe : 139,789 Ha

Assuming 10 odt/Ha/yr yield and fuelling 1 MWe with 5000odt/year.

This would effectively absorb all the land becoming nationally available following CAP reform.

(5) To meet the biomass co-fired capacity requirements of Portfolios 1-4 alone for 2020 it will be necessary to utilise about 28,700Ha of Short Rotation Coppice in addition to 2 million tonnes of mixed forest biomass if the projections of Table A6.1 are borne out.

(6) However the fuel available from these projections would appear to be swallowed up by the requirement of Ref. (63) that wood should fuel 12% of heating needs which, assuming a linear increase in demand from 2010 would suggest a biomass demand for that year of 725.3ktoe to be met by 3.95 – 5.35Mt of wood (depending on moisture content) for heating alone.

(7) Taken with the shortfall in planting over the past few years which has now reached a backlog of 100,000Ha relative to the 1996 Strategic Plan, a relatively balanced market situation and other attractions for available land resources (biofuels), it seems clear that a significant balancing dependence on imports will arise. Although there is scope for the market to adjust within itself in the short term (via increased thinnings), in the longer term only a return to an increased level of planting is sustainable as demonstrated by COFORD forward projections.

(8) Levelised cost projections are as summarised on Table A6.4.

A6.13 Recommendations

It should be noted that, with prioritisation, the fuel requirements of Portfolios 1-6 can technically be met by a combination of forest material and biomass which will involve imports if the heating requirements are as projected. While technically possible the economics of such arrangements are uncertain at present.

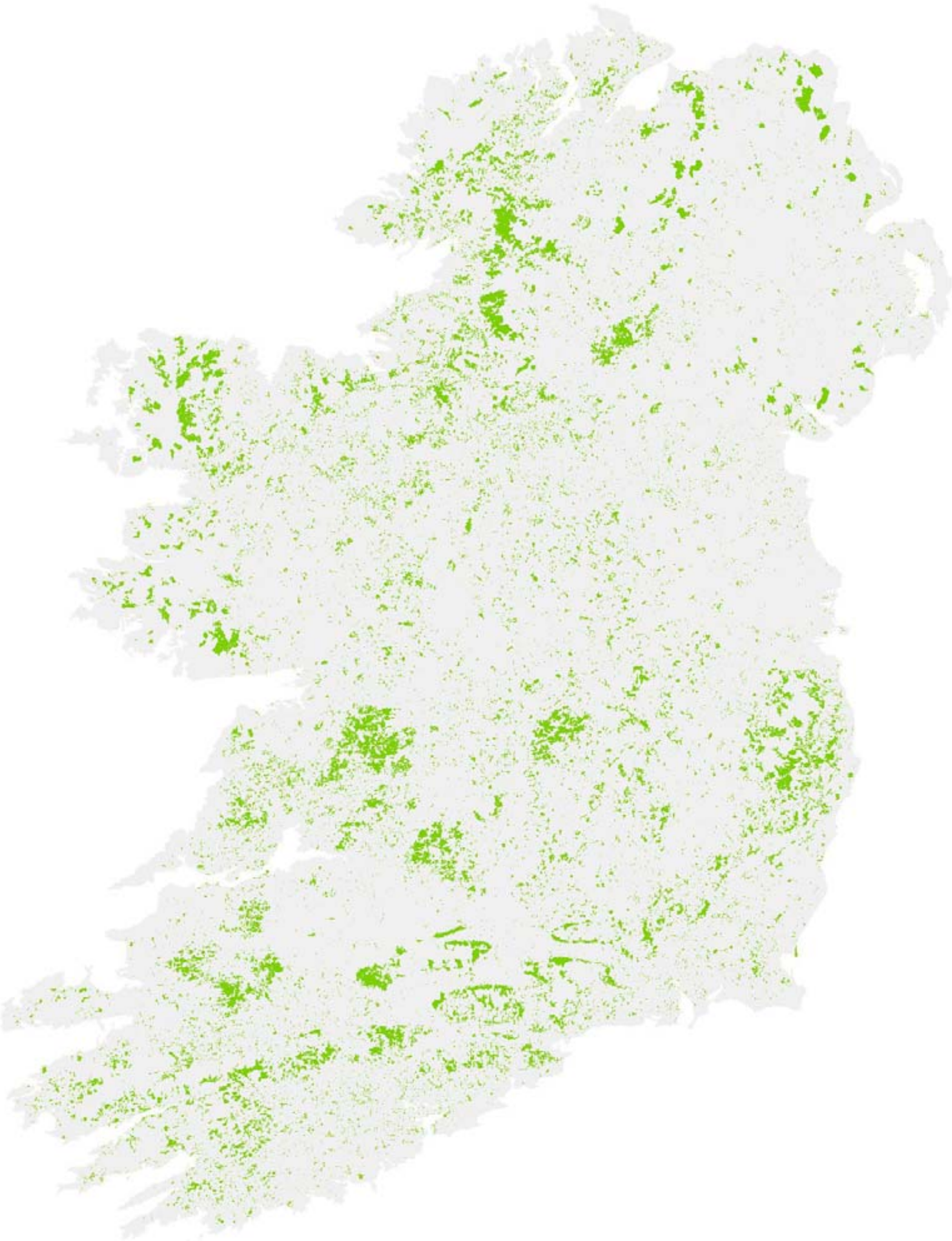


Figure A6.1 - Forest Resource Distribution

Figure A6.2 - Short Rotation Coppice Area as a function of Cofiring Capacity

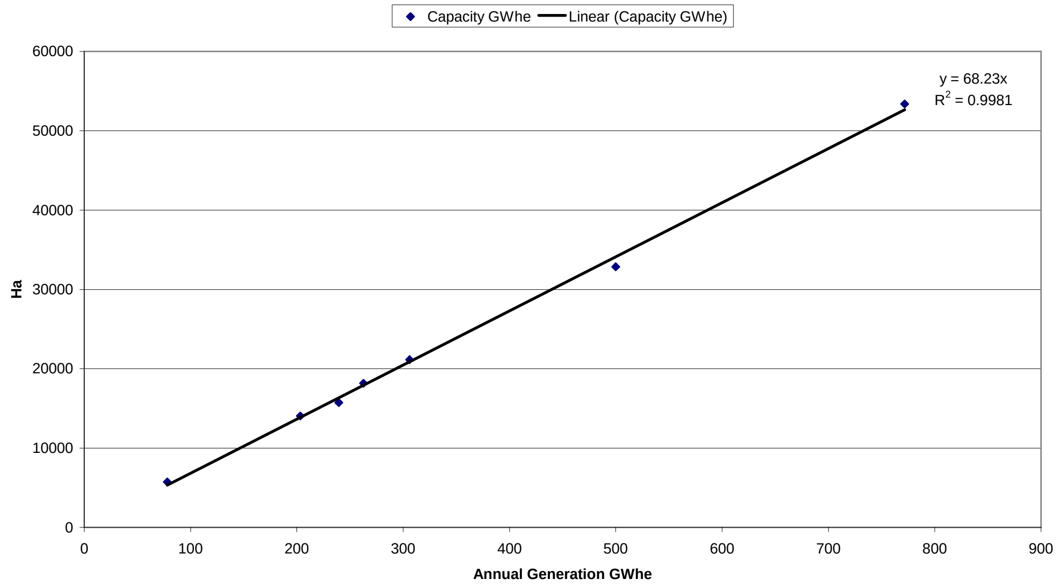


Figure A6.3 - Short Rotation Coppice Area as a function of Cofiring Capacity

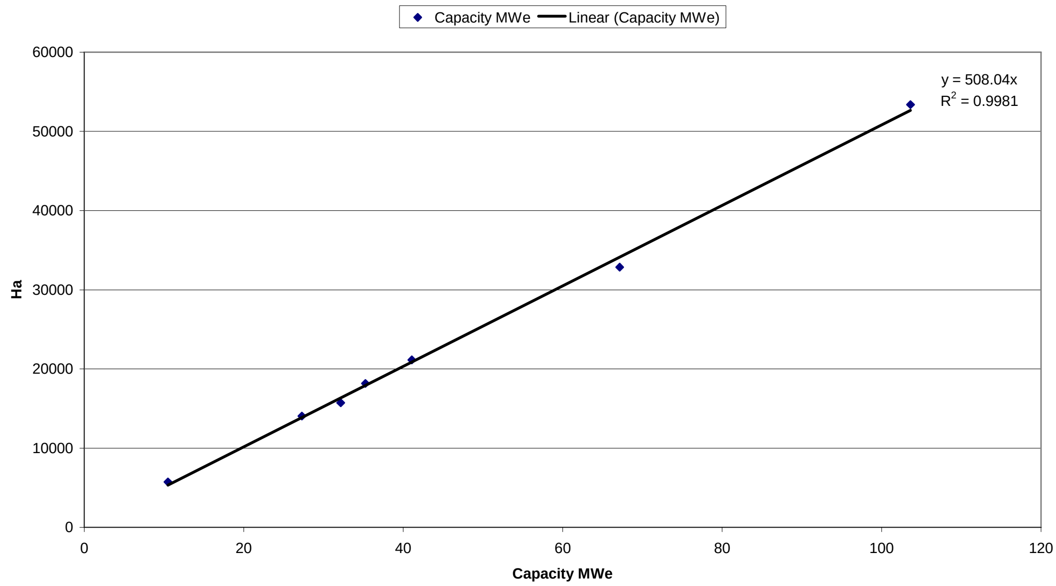


Figure A6.4 - Recent Afforestation Records

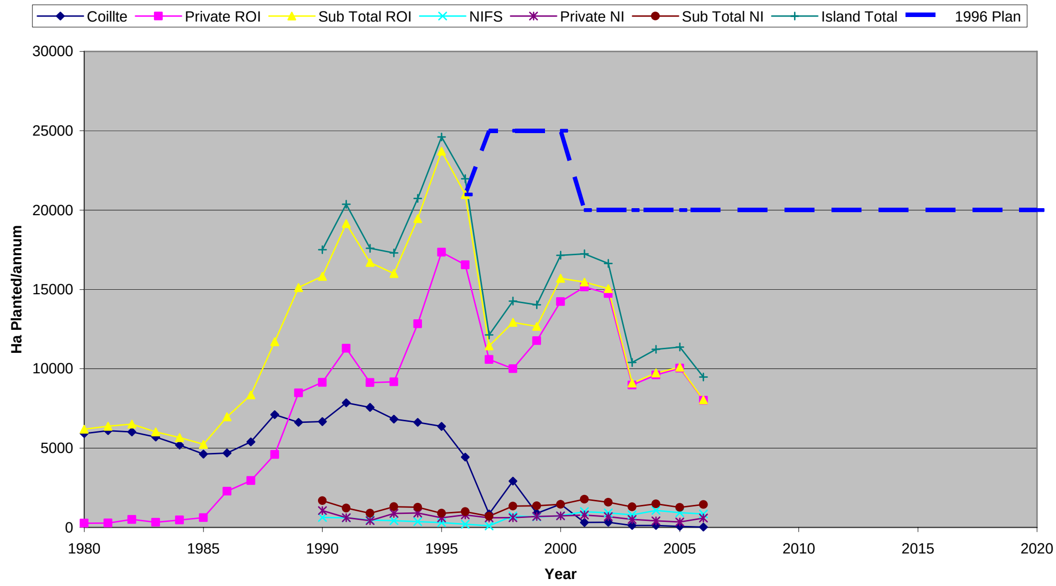


Figure A6.5 - Afforestation Aggregate Planting Since 1996 - Hectares

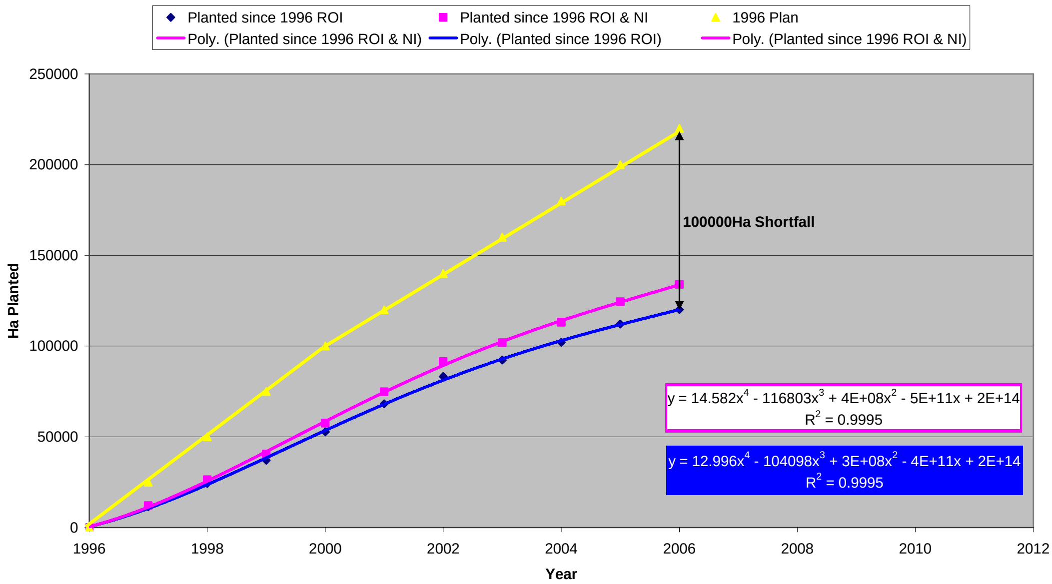
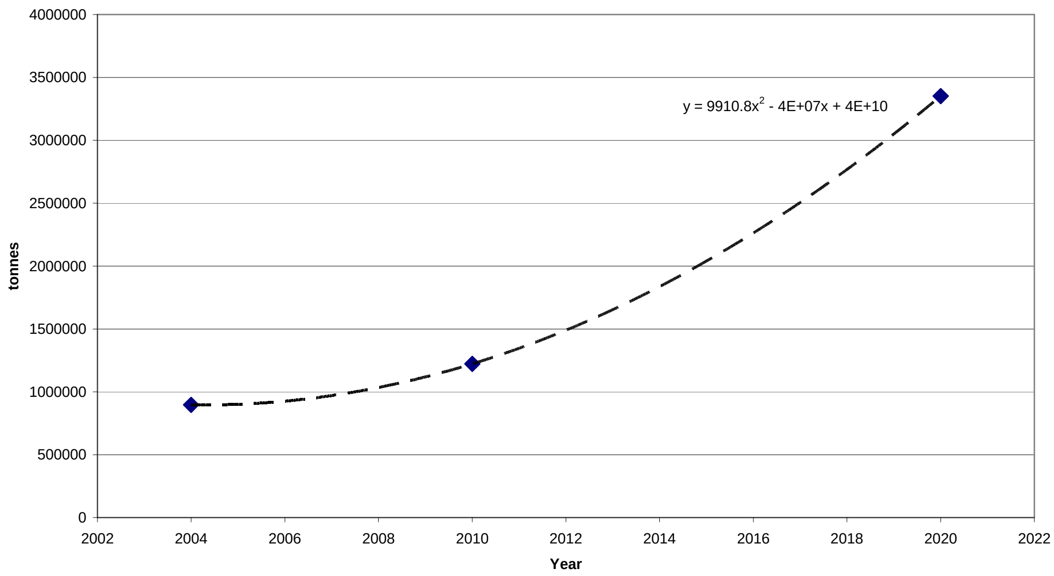


Figure A6.6 - Projected Biomass Required for Heat Market



Appendix 7

Wind Energy Resource

A7.1 Introduction

The wind energy resource in the Republic of Ireland was initially estimated in 1996-7 as part of the input to "Total Renewable Energy Resource in Ireland, Ref (29). ESB International and the UK Energy Technology Support Unit (ETSU) estimated the extent of the wind resource of the Republic of Ireland using methodology that had already been applied in Northern Ireland, Scotland and parts of England based on the NOABL wind model developed in the United States. In this application the model was applied at a height of 45m above ground. It utilised a 1km square grid of points for which calculations were made based on input from Met Eireann stations and an averaged wind rose for the whole country.

During the period 1997-2001, feedback reaching the Renewable Energy Information Office via a series of seminars that involved representatives of local planning authorities, wind farm developers, consultants and others, together with a number of publications, most notably "Micrositing with Mesomap (Ref 46) and "Offshore Electricity Generating Stations – Note for Intending Developers (Ref 47), led to an emphasis on the need for county based wind resource mapping for planning purposes. This would take account, where possible, of the wind measurements being made at heights above the standard meteorological height by developers and others at prospective wind farm sites. New methods of analysis were also becoming available and the (then) Dept. of Energy issued an Enquiry dated Sept. 2001 that invited tenders for the determination of the onshore commercially accessible wind energy resource on a national and a county basis, in the form of both the unconstrained theoretical resource and the feasible commercial resource constrained by physical limitations.

ESBI International, with TrueWind Solutions were in 2002 contracted to Sustainable Energy Ireland to develop wind resource mapping for both onshore and offshore application in the Republic of Ireland. Using its MesoMap system, TrueWind Solutions produced grid data files of mean wind speed, speed and direction frequency distribution parameters and wind power at heights of 50 m, 75 m, and 100 m above ground, on a 200 m grid covering the Republic of Ireland and points up to 20 km offshore on a 400m grid. From this ESB International produced individual digital county and offshore wind resource maps.

In the derivation of the raw data files the method employed is based, inter alia, on the use of a historical world weather dataset compiled for intervals of six hours at all atmospheric levels. Analysis is then performed using nested grids of successively finer mesh size to simulate conditions down to a grid size of 1km. The mesh size is further reduced using a second model having regard to local land elevation, land cover and roughness and a comparison is made between the predicted wind characterisation and those measured at a range of meteorological sites across the country to minimise the residual differences between predicted and actual mean values encountered.

The results confirmed that Ireland has a very significant wind resource, particularly offshore, at exposed points along the coasts, and on hilltops and ridges throughout the island and especially in the western part of the country. The predicted mean wind speed in many such locations is in the range of 8 to 10 m/s, which would indicate to support economical wind energy projects. Lowlands and valleys are somewhat less windy, with mean wind speeds predicted to be in the range of 6 to 7.5 m/s.

Subsequently in 2003 following on from the success of the Wind Atlas for the Republic of Ireland, the Department of Enterprise Trade and Investment Northern Ireland contracted ESB International with TrueWind Solutions to produce similar wind resource mapping for Northern Ireland for both onshore and offshore application.

A7.2 Methodology

A7.2.1 Mesomap System

At the core of the MesoMap system is MASS (Mesoscale Atmospheric Simulation System), a numerical weather model that has been developed over the past 20 years both as a research tool and to provide commercial weather forecasting services. MASS embodies the fundamental physics of the atmosphere including conservation of mass, momentum, and energy, as well as the moisture phases, and it contains a turbulent kinetic energy module that accounts for the effects of viscosity and thermal stability on wind shear. As a dynamical model, MASS simulates the evolution of atmospheric conditions in time steps as short as a few seconds. This creates great computational demands requiring the use of powerful workstations and multiple parallel processors. However, MASS can be coupled to a faster model, WindMap, a high-resolution mass-consistent wind flow model. Depending on the size and complexity of the region and requirements of the client, WindMap may be used to increase the spatial resolution of the MASS simulations.

A7.2.2 Meteorological Databases

The MASS model uses a variety of online, global, geophysical and meteorological databases. The main meteorological inputs are reanalysis data, rawinsonde data, and land surface measurements. The reanalysis database – the most important – is a gridded historical weather data set produced by the US National Center for Environmental Prediction (NCEP) and National Centre for Atmospheric Research (NCAR). The data provides a snapshot of atmospheric conditions around the world at all levels of the atmosphere in intervals of six hours. Along with the rawinsonde and surface data, the reanalysis data establish the initial conditions as well as updated lateral boundary conditions for the MesoMap simulations. However, the model itself determines the evolution of atmospheric conditions within the region based on the interactions among different elements in the atmosphere and between the atmosphere and the surface. Because the reanalysis data are on a relatively coarse, 200 km grid, the MesoMap system is run in several nested grids of successfully finer mesh size, each taking as input the output of the previous nest, until the desired grid scale is reached. The outermost grid typically extends several thousand kilometers.

The main geophysical inputs are elevation, land cover, vegetation greenness (normalized differential vegetation index, or NDVI), soil moisture, and sea-surface temperatures. The elevation data normally used by MesoMap were produced by the US Geological Survey* in a gridded digital elevation model, or DEM, format from a variety of data sources. The US Geological Survey, the University of Nebraska, and the European Commission's Joint Research Centre (JRC) produced the land cover data in a cooperative project. The land cover classifications are derived from the interpretation of Advanced Very High Resolution Radiometer (AVHRR) data – the same data used to calculate the NDVI. The model translates both land cover and NDVI data into biophysical parameters such as surface roughness, albedo, emissivity, and others. The nominal spatial resolution of all of these data sets is 1 km. Thus, the standard output of the MesoMap system is a 1 km gridded wind map, although higher resolution maps can be produced if the necessary topographical and land cover data are available.

A7.3 Computer and Storage Systems

The MesoMap system requires a very powerful set of computers and storage systems to produce wind resource maps at a sufficiently high spatial resolution and with a fast turnaround time. To meet this need TrueWind Solutions created a distributed processing network consisting of 94 individual Pentium II processors and 2.5 Terabytes of hard disk storage. Since each processor simulates a sequence of days independently from the others, a project can be run on this system 50 times faster than would be possible with any single processor. To put it another way, a typical MesoMap project requiring 2 CPU-years of processing can be completed in just 2 weeks. The typical project also generates around 500 GB of data.

A7.4 The Mapping Process

The MesoMap system creates a wind resource map by simulating weather conditions over 366 days selected from a 15-year period. The days are chosen through a stratified random sampling scheme so that each month and season is represented equally in the sample. Each simulation generates wind and other weather variables (including temperature, pressure, moisture, turbulent kinetic energy, and heat flux) throughout the model domain, and the information is stored at hourly intervals. When the runs are finished, the data files are compiled and summarized in a variety of formats, including most importantly colour-coded maps of mean wind speed and power density at various heights above ground and databases containing wind frequency distribution parameters. The results are then compared with available land surface and ocean surface wind measurements, and if significant discrepancies are observed, adjustments can be made to the wind maps or the runs may be repeated with a different model configuration to iron out any shortcomings.

A7.5 Accuracy of the Method

TrueWind has compared the MesoMap predictions with high-quality measurements from tall towers in several regions and climates (Ref 46). These comparisons indicate that the standard error in mean wind speed is usually 7% or less once the

* The US Defence Department's high-resolution Digital Terrain Elevation Data set is the principal source for the global 1km grid elevation. Gaps in the DTED data set were filled mainly by an analysis of 1:1,000,000 scale elevation contours in the Digital Chart of the world (now called VMAP). For Ireland the Ordnance Survey 50m grid digital terrain model was used (See 5.1), giving a much higher resolution.

uncertainty in the data is removed. One or more of the following factors, which are listed in approximate order of decreasing importance, usually drives the errors:

- Variations in topography and land cover not resolved at the model grid scale
- Errors in the land cover data bases
- Finite sample size
- Errors in the meteorological data

The first is usually the most important. With a sufficiently high resolution at both the MASS and WindMap scales, it has been found that the model-only standard error can usually be reduced to around 3-7%. What resolution is “sufficiently high” depends on several factors including the complexity of the terrain and whether there are any land-ocean boundaries within the domain being mapped. Even where a higher resolution is clearly desirable, however, budgetary and schedule considerations may limit the ability to reduce the grid spacing of the model runs.

Errors in the land cover data, and especially the translation to surface roughness, are the next most common problem. These errors can usually be reduced or eliminated by applying site-specific adjustments to the surface roughness based on field surveys and aerial photography. (The method is described in Section 5 below).

The finite sample size (366 independent days) introduces an error margin of, typically, 3-4%. However the uncertainty can be larger where the wind speed frequency distribution is unusually broad – for example, if the wind resource varies greatly by season.

Errors in the meteorological data are probably of little concern in most developed countries, but may be significant in developing countries where data collection is relatively sparse.

A7.6 Wind Resource

A7.6.1 Wind Maps

The resultant wind maps show the predicted mean wind speed at heights of 50 m, 75 m and 100 m above ground level and also show the predicted mean wind power density at the same heights. The mean speed and power describe different aspects of the wind resource, and both can be useful in different ways. The mean speed is the easier for most people to relate to and is consequently the more widely used. However, it does not directly measure the power-generation potential in the wind. Some experts regard the mean wind power, which depends on the air density and the cube of the wind speed, as a more accurate indicator of the wind resource when assessing wind project sites. Generally speaking, commercial wind power projects using large turbines require a mean speed of at least 7 m/s or mean power of at least 400 W/m^2. Small turbines are designed to operate at lower wind speeds, and may be useful at mean speeds (at 30 m height) as low as 5-6 m/s.

The wind speed map depicts a widely varying wind resource. The main factors affecting the resource are distance from the coast, exposure above the surrounding terrain, and land cover (which determines surface roughness).

The data files referred to earlier include the predicted speed and power at 50, 75 and 100 m heights above ground. Also included in these data files at each respective height are the wind speed frequency distribution factors (described using Weibull parameters, A & k) and direction frequency distributions (12 directional sectors). The predicted wind shear exponent generally ranges from 0.18 to 0.21 in open areas on land and from 0.26 to 0.30 in forested or sheltered areas. Offshore, the predicted shear exponent is about 0.11 off the west coast and 0.13 in the Irish Sea. The higher shear on the eastern side reflects not only the frictional effect of the land, but also more frequent thermal stability in the boundary layer.

For both the Republic of Ireland and Northern Ireland projects, digital terrain elevation data on a 50 m grid spacing from Ordnance Survey Ireland (OSI) and Ordnance Survey Northern Ireland was used. The elevation map was then resampled using bilinear interpolation to the final 200 m grid scale. To define the surface roughness, roughness contours were prepared from the CORINE land cover database by ESBI International, amplified in forest areas, by a forest growth database produced by the Irish Forest Service (ROI) and Department of Agriculture and Rural Development in Northern Ireland. Upwards of one thousand sample observations of ground roughness were made throughout Ireland to validate the process.

The MASS model was run over nested grids at three grid scales: 30 km, 8 km, and 2 km and subsequently the Windmap model was run at a grid scale of 200 m.

A7.6.2 Map Validation and Adjustments

The wind maps were initially produced without reference to any surface wind data. To assess the maps' accuracy, the 50 m height mapped wind speed values were compared with data from 34 monitoring stations throughout the Republic of Ireland, and 11 stations in Northern Ireland. They included 14 stations maintained by Met. Éireann, 7 stations maintained by the UK Meteorological Service. The instruments at most of the met service stations were mounted on towers or buildings at the standard height of 10 or 12 m, except Malin Head, which was at 21 m. In addition data for 24 stations owned by private developers was available; tower heights for these stations ranged from 10 m to 50 m. Unlike the met stations, which with few exceptions were located in lowlands and valleys, the privately owned towers were located mainly on hilltops of possible interest for wind energy projects. The core ten year period of interest was 1990-9 inclusive.

It is useful to note that ten years of hourly data reported from one meteorological station gives rise to 82,600 values from which a distribution and mean value is determined. Thus what appears as a single point source is in fact much wider in that it forms part of a simultaneous set that reflects the wind behaviour during the decade of measurement. Wind patterns can oscillate and drift over the years so that some differences between short term and long term measurements are always to be expected, independent of those induced by changes in ground roughness to which measurements made at 10m height (meteorological stations) are particularly vulnerable.

The available periods of measurement varied widely among the stations. Almost 30 years of annual mean speed values, starting in 1972, were available for the Meteorological Eireann and UK Meteorological Service stations. In contrast, most of the privately owned towers were monitored for only a year or two in the early or middle 1990s before being dismantled. It was necessary to ensure Summer/Winter time and US/European recording conventions are treated consistently in privately recorded data. Where possible, adjustments were made to the mean speeds recorded at the short-term stations using regressions against nearby met stations. However the accuracy of these adjustments was in some cases limited by the poor correlation between the currently available short-term and long-term station data and apparent fluctuations or trends in the long-term data. Where this occurred the data from the private sites was discarded. The significance of this problem should reduce with time as more data of higher quality is collected by private developers.

The validation procedure was carried out using the following steps:

1. Station locations were verified and adjusted, if necessary, by comparing the quoted elevations and station descriptions against the elevation and land cover maps. Where there was an obvious error in position, the station was migrated to the nearest point with the correct elevation or other characteristic.
2. The observed mean speed and power were extrapolated to a common reference height of 50 m using the power law. For those privately owned stations that had multiple levels of instruments, the measured wind-shear exponent was used. For particular Met Éireann and UK Meteorological Service stations, the shear exponent was derived from WASP analyses reported in the European Wind Atlas (Ref 48), which took into account localized influences on the measured wind speed (such as nearby buildings) at these stations. The shear exponent for the remaining stations was estimated from the surrounding land cover and topography. The average shear exponent for the privately owned stations was 0.18, with a range of 0.10 to 0.23; the average for the met stations was 0.21, with a range of 0.10 to 0.28.
3. The error margin for each data point was then estimated as a function of two factors: the tower height and the number of years of measurement. Although these are not the only sources of uncertainty, they are the most easily quantified.

The tower height enters the equation because of uncertainty in the wind shear. An error margin in the shear equal to 15% of the estimated shear exponent was assumed; for example, if the estimated shear was 0.2, the error margin was assumed to be 0.03.

The number of years of measurement affects the reliability of the long-term mean wind speed estimate. The wind speed measured over a short period may not be representative of long-term conditions. An indicative guide in the wind industry is that a mean speed based on one year of data will be within 10% of the true long-term mean with 90% confidence. This translates into a standard error of 6% for one year of data. It was assumed that the annual mean fluctuates randomly with a normal distribution, and thus the error margin varies inversely with the square root of the number of years.

The two uncertainties were then combined in a least-squares sum as follows:

$$(1)\quad e = \sqrt{\left(\left(50/H\right)^{0.15\alpha} - 1\right)^2 + \left(\frac{0.06}{\sqrt{N}}\right)^2}$$

where H is the height of the anemometer, α the estimated shear exponent, and N the number of years of measurement. For example, if the mean speed for a 10 m tower with a two-year record was 4.6 m/s, and the estimated shear was 0.18, then the estimated 50 m speed would be 6.1 m/s with a standard error of 6.1%, or 0.4 m/s.

This equation shows that, as might be expected, that the dominant source of uncertainty for the met stations is the extrapolated wind shear, whereas the dominant source of uncertainty for the privately owned stations is their relatively short period of record.

Next, the predicted and measured/extrapolated speed and power were compared, and the map bias (map speed or power minus measured/extrapolated speed or power) was calculated for each point. The results were then displayed in a scatter plot, which allows the quick identification of outlying points and reveals the overall quality of the match between prediction and measurement.

Table A7-1 and A7-2 summarise the results. Figure A71 and A7-2 shows a scatter plot comparing the data against both the preliminary and final maps. For the preliminary map, the predicted mean wind speeds were on average about 0.3 m/s higher than the measured/extrapolated values for the Republic of Ireland (ROI) and 0.5m/s for Northern Ireland (NI). The corresponding root-mean-square discrepancy was 0.5 m/s for both, or about 6% for ROI and 7% for NI of the average speed. The RMS discrepancy reflects errors both in the model and the data, however, and therefore tends to overstate the true error in the predicted mean wind speed. The true error can be estimated by subtracting (in a least-squares sense) the standard error of the data (eDATA) from the total RMS discrepancy (eTOTAL), as follows:

$$(2)\ e_{MODEL} \approx \sqrt{e_{TOTAL}^2 - e_{DATA}^2}$$

This equation assumes that the errors in the model and data are random, normally distributed, and independent of one another. Using this equation, the speed error for the model alone (preliminary results) is found to be 0.4 m/s, or 5% of the average speed for ROI and 5.5% for NI.

The scatter plot (Figure A7-1) shows that most of the high bias in the preliminary results occurred at stations with relatively low wind speeds, which were mainly met stations in the central part of Ireland such as Kilkenny and Birr. It is possible that problems in measuring equipment or tree growth/buildings nearby, could be causing anomalously low readings under low wind conditions at some of these stations; and indeed some of the data exhibit a rather high incidence of calms and low speeds that does not follow a normal frequency distribution. The wind shear at these stations could also be higher than estimated. Nevertheless, it seemed prudent to rerun the final stage of the mapping process with modified settings to increase the nocturnal stability and shear, and hence lower the near-surface wind speed, at the less windy stations.

In Northern Ireland Table A7-2 shows that the largest discrepancies occur at the Belfast Harbour, Hillsborough, and Glen Anne met stations. With the exception of Belfast Harbour, the tendency is for the model to overestimate the wind speed at the met stations. It is difficult to say whether this pattern is caused by problems with the wind map or with the data.

While it is certainly possible that the model could overestimate the wind resource, particularly in sheltered locations; however it is also plausible that problems in the measuring equipment, such as friction in the bearings, could be causing anomalously low readings under low wind conditions at some of these stations, and that the masts may in some cases be sheltered by buildings or trees. Based on the evidence, we concluded that no adjustments to the maps were required.

The result for ROI is shown in the last two columns of Table A7-1 and in the square dots in Figure A7-1. Error bars have been added to show the error margin of the data calculated using Equation 1. The average bias of the final map is now near zero, while the root-mean-square discrepancy has been reduced to 0.4 m/s, or 5%.

This is only slightly higher than the average error margin of the data, and thus the model-only error is just 0.2 m/s, or about 2.5%.

The linear trend line, which is forced through the origin, confirms that the average measured/extrapolated speed nearly equals the predicted, while the r2 correlation coefficient of 88% shows that the model explains the vast majority of the variance in the observed wind resource. Thus concluded the second or analytical stage of the project.

Table A7-1.

Comparison of measured/extrapolated and predicted mean wind speeds at 50 m (ROI).

Station Name	Anem. Height (m)	Obs. Speed (m/s)	Shear Exp.	Obs. Speed at 50m (m/s)	Est. Error Margin (m/s)	Prelim. Map (m/s)	Prelim. Map Bias (m/s)	Final Map (m/s)	Final Map Bias (m/s)
Orsay Lighthouse	10	8.0	0.10	9.4	0.3	9.3	-0.1	9.4	0.0
Malin Head	21	8.3	0.10	9.1	0.2	8.9	-0.1	8.8	-0.3
Proprietary	34.5	9.5	0.10	9.8	0.3	10.5	0.6	10.5	0.7
Proprietary	30	7.1	0.30	8.2	0.3	8.7	0.4	8.5	0.3
Proprietary	25	9.2	0.13	10.1	0.5	9.5	-0.6	9.4	-0.7
Proprietary	41	9.5	0.23	10.0	0.3	9.7	-0.3	9.6	-0.4
Proprietary	41	8.4	0.18	8.7	0.3	8.6	-0.1	8.7	-0.1
Bellmullet	12	6.9	0.16	8.7	0.3	8.7	0.0	8.8	0.1
Clones/	10	4.1	0.28	6.4	0.5	6.8	0.4	6.3	-0.1
Proprietary	30	9.0	0.15	9.7	0.3	9.6	-0.1	9.8	0.0
Proprietary	30	7.5	0.17	8.2	0.3	9.2	1.0	8.8	0.6
Proprietary	50	8.0	0.25	8.0	0.2	8.3	0.3	7.6	-0.4
Mullingar	12	4.6	0.24	6.5	0.4	7.3	0.8	6.9	0.4
Dublin	12	5.2	0.22	7.1	0.4	7.5	0.4	7.0	-0.2
Casement	10	5.9	0.22	8.4	0.5	8.2	-0.2	7.7	-0.7
Birr	10	3.6	0.28	5.6	0.4	7.1	1.4	6.6	0.9
Proprietary	30	7.8	0.15	8.4	0.3	8.6	0.2	8.4	0.0
Shannon Apt.	12	5.0	0.22	6.8	0.4	7.1	0.2	6.8	-0.1
Kilkenny	12	3.5	0.28	5.2	0.3	6.5	1.3	6.1	0.9
Proprietary	40	9.0	0.18	9.4	0.4	9.1	-0.3	9.0	-0.4
Rosslare	10	5.8	0.21	8.1	0.5	8.2	0.1	8.1	0.0
Proprietary	40	8.9	0.18	9.3	0.3	9.0	-0.3	8.8	-0.4
Proprietary	30	8.1	0.21	9.0	0.3	8.9	-0.1	8.8	-0.2
Proprietary	30	7.7	0.19	8.5	0.3	8.9	0.4	8.9	0.4
Proprietary	40	7.6	0.17	7.9	0.5	8.2	0.3	7.7	-0.2
Valentia Obs	12	5.7	0.23	7.9	0.4	8.2	0.3	7.8	-0.1
Cork Airport	12	5.8	0.20	7.8	0.4	8.2	0.4	7.7	-0.1
Proprietary	40	8.5	0.13	8.8	0.3	9.5	0.7	9.4	0.6
Proprietary	40	7.9	0.10	8.1	0.3	8.6	0.5	8.6	0.5
Proprietary	10	6.9	0.17	9.1	0.5	9.3	0.2	8.9	-0.2
Roches Point	12	6.3	0.15	7.8	0.3	8.3	0.5	7.7	-0.1
Claremorris	12	4.6	0.28	6.9	0.4	7.7	0.9	7.3	0.4
Proprietary	30	8.3	0.17	9.0	0.3	9.3	0.2	9.2	0.2
Proprietary	30	8.0	0.18	8.8	0.3	9.1	0.4	8.8	0.1
Average (m/s)				**8.3**	**0.3**	**8.5**	**0.3**	**8.3**	**0.0**
RMS Discrepancy (m/s)							**0.5**		**0.4**
Model-Only Error (m/s)							**0.4**		**0.2**

Table A7-2.

Comparison of observed and predicted mean wind speeds at 50 m (NI).

Station Name	Anem. Height (m)	Obs. Speed (m/s)	Est. Shear Exp.	Obs. Speed at 50m (m/s)	Est. Error Margin (m/s)	Map (m/s)	Map Bias (m/s)
Proprietary	41	9.5	0.23	10.0	0.33	9.8	-0.2
Proprietary	25	9.2	0.13	10.1	0.48	10.2	0.2
Proprietary	41	8.4	0.18	8.7	0.27	9.0	0.3
Proprietary	40	8.9	0.13	9.2	0.55	8.7	-0.5
Saint Angelo	10	3.8	0.33	6.4	0.36	6.5	0.2
BallyPatrick Forest	10	4.6	0.33	7.8	0.44	8.3	0.5
Eglinton/Londonderry	10	5.2	0.23	7.5	0.30	7.3	-0.2
Hillsborough	10	3.6	0.33	6.1	0.35	6.7	0.6
Belfast/ Aldergrove	10	4.5	0.27	7.0	0.33	7.3	0.3
Belfast Harbor	10	4.4	0.27	6.8	0.32	6.2	-0.6
GlenAnne	10	4.5	0.26	6.9	0.31	7.9	1.0
Average (m/s)				**7.2**	**0.4**	**7.4**	**0.1**
RMS Discrepancy (m/s)							**0.5**
Model-Only Error (m/s)							**0.4**

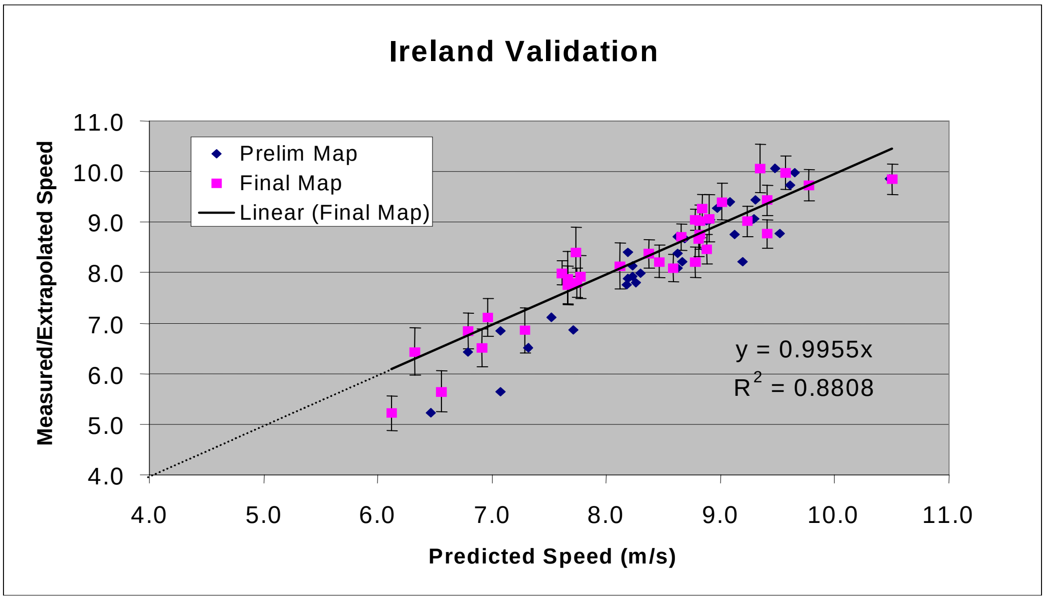


Figure A7-1 – Scatter plot of predicted and measured wind speeds for Republic of Ireland. The error bars are calculated from the equation given in the text.

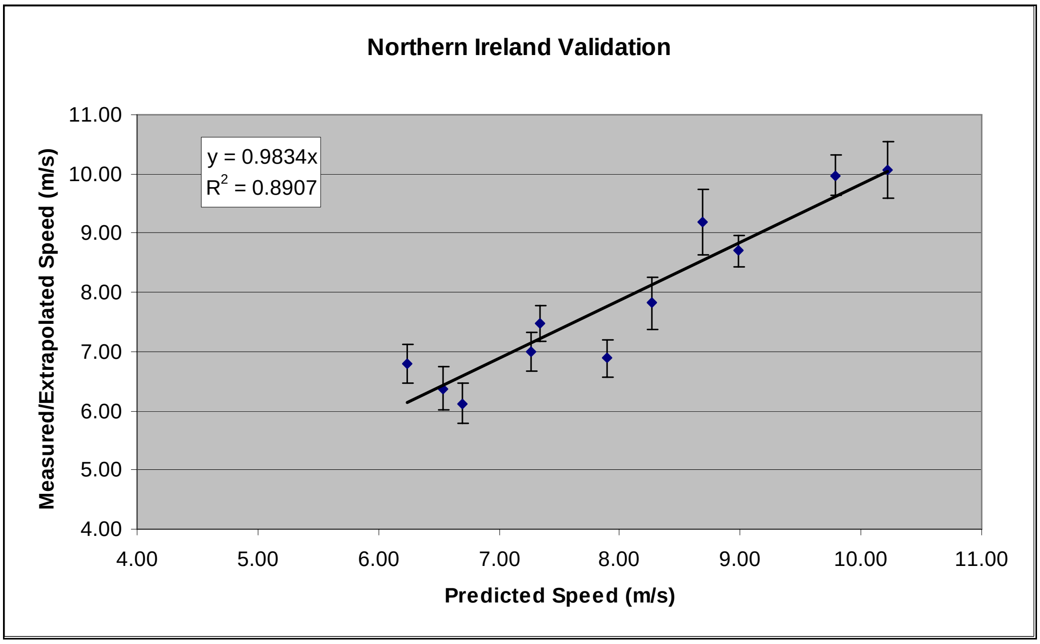


Figure A7-2 - Scatter plot of predicted and measured wind speeds in Northern Ireland. The error bars are calculated from the equation given in the text.

With regard to the diurnal graphs it may be noted that nocturnal stability has the effect of reducing turbulence and friction between different atmospheric layers. This reduction in friction however strengthens the influence of the force acting on the atmosphere due to the rotation of the earth (Coriolis force) giving rise to an oscillating increase in wind speed with height which is proportional to the latitude of the particular point on the earth's surface. There is evidence of this in the project diurnal windspeed distributions between heights of 50m and 100m. While good agreement was obtained between measured and projected distributions at the lower heights there were no field measurement records accessible for the relevant period at heights of 100m or more as diurnal data from instruments originally attached to tall structures such as television masts and shipyard cranes were no longer available. This is a matter for future attention as the influence of sustained nocturnal winds at height will affect the capacity factors of future large turbines in a positive way.

Following correction of a slight problem (originally identified in the diurnal data) arising from the way in which rawinsonde and surface data were assimilated into the model for midnight and midday (allowing for local summer time) the hourly means were renormalized as well. The projected mean wind speeds for each day and hour of the synthesised year reflect this correction. The projected mean annual values as mapped are also derived from corrected figures.

A7.7 Conclusions (Wind Atlas ROI & NI)

A7.7.1 Onshore Resource

(1) Using the MesoMap system, highly detailed wind resource maps and data files have been produced for both the Republic of Ireland and Northern Ireland. The results confirm that Ithe island of reland has a very good wind resource. Sites with a sufficient mean wind speed to support economical wind projects are predicted to be found on hilltops and mountaintops throughout the country, in open areas with few trees in the western part of the country, on exposed points near the coasts, and offshore. The preliminary MesoMap results agreed very closely with data from 45 wind monitoring stations, apart from some overestimation of the resource at less windy stations in the central part of the country. However the revised model runs eliminated the overall bias, resulting in an estimated standard error of prediction versus measurement of about 2.5%.

(2) The results gave mean wind speed, power density, directionality diurnal, seasonal effects and wind speed distributions at each of the required heights (50m, 75m, 100m) as calculated from the data set on a grid of 200m spacing. In order to attain smooth contours along the county boundaries this implies inclusion of some predicted values from outside the country area. This grid spacing is five times finer than the 1km grid specified at the outset and produces maps of correspondingly higher resolution.

(3) For the purposes of this study the Meso Map system provides a suitable method for estimating the wind energy resource North and South as described in Section 2 of this report. The results in terms of meeting the respective Portfolios are given in Tables A7.7.1-4 which follow.

Table A7.7.1

2020 Wind Farm Developments to meet Portfolio 1

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
1	Connected	60	Agannygal		74	Contracted	8.75	Larne Main
2	Connected	19.5	Booltiagh		75	Contracted	5.1	Strabane Main
3	Connected	42.5	Coomagearlaghy		76	Contracted	9	Strabane Main
4	Connected	31.5	Crane		77	Contracted	10.5	Strabane Main
5	Connected	23.8	Cunghill		78	Contracted	5.2	Limavady Main
6	Connected	71	Drumkeen		79	Contracted	54	Enniskillen Main
7	Connected	15	Golagh		80	Contracted	60	Arklow
8	Connected	2.55	Ardnacrusha		81	Contracted	51	Athea
9	Connected	0.66	Ardnacrusha		82	Contracted	41.2	Coomacheo
10	Connected	4.8	Arigna		83	Contracted	29.8	Glanlee
11	Connected	5	Arigna		84	Contracted	14	Meentycat
12	Connected	1.2	Arigna		85	Contracted	21.9	Moneypoint
13	Connected	25.2	Arklow		86	Contracted	37.8	Pallas
14	Connected	8.5	Ballylickey		87	Contracted	24.8	Ratrussan
15	Connected	4.5	Bandon		88	Contracted	70	Ratrussan
16	Connected	6.45	Bellacorick		89	Contracted	7.5	Ardnacrusha
17	Connected	0.66	Binbane		90	Contracted	19.6	Ballylickey
18	Connected	2.55	Carlow		91	Contracted	15	Binbane
19	Connected	2.1	Castlebar		92	Contracted	6	Binbane
20	Connected	3.4	Castlebar		93	Contracted	2.6	Binbane
21	Connected	18.7	Castlebar		94	Contracted	7.7	Binbane
22	Connected	3.08	Cath_Fall		95	Contracted	11.9	Binbane
23	Connected	3.4	Cath_Fall		96	Contracted	1.7	Butlerstown
24	Connected	7.65	Corderry		97	Contracted	5	Carlow
25	Connected	3.4	Corderry		98	Contracted	3.4	Corderry
26	Connected	6.8	Corderry		99	Contracted	7.5	Dundalk
27	Connected	4.95	Corderry		100	Contracted	10.5	Glenlara
28	Connected	3.96	Corderry		101	Contracted	5.1	Letterkenny
29	Connected	4.99	Crane		102	Contracted	14.5	Lodgewood
30	Connected	2.55	Dallow		103	Contracted	5	Lodgewood
31	Connected	4.25	Dallow		104	Contracted	15	Macroom
32	Connected	1.7	Drybridge		105	Contracted	20	Mallow
33	Connected	5.95	Dunmanway		106	Contracted	6	Moy
34	Connected	4.62	Dunmanway		107	Contracted	5	Rathkeale
35	Connected	4.25	Dunmanway		108	Contracted	2.5	Rathkeale
36	Connected	5.94	Dunmanway		109	Contracted	5	Rathkeale
37	Connected	0.675	Galway		110	Contracted	3	Shankill
38	Connected	3.3	Galway		111	Contracted	0.6	Sorne Hill

Table A7.7.1

2020 Wind Farm Developments to meet Portfolio 1

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
39	Connected	26	Glenlara		112	Contracted	31.5	Sorne Hill
40	Connected	2.55	Ikerrin		113	Contracted	15	Tralee
41	Connected	2.55	Ikerrin		114	Contracted	1.7	Tralee
42	Connected	9.35	Knockeragh		115	Contracted	15.3	Tralee
43	Connected	15	Letterkenny		116	Contracted	22.5	Trien
44	Connected	4.98	Letterkenny		117	Contracted	7.6	Trien
45	Connected	11.88	Letterkenny		118	Contracted	14	Trillick
46	Connected	2.55	Letterkenny		119	Contracted	10.2	Trillick
47	Connected	2.45	Letterkenny		120	Contracted	20.3	Wexford
48	Connected	10.5	Meath		121	Contracted	6.8	Wexford
49	Connected	4.5	Meath		122	In Planning	75	Lisaghmore Main
50	Connected	3	Shankill		123	Unsigned Grid App	4.5	Moy
51	Connected	7.65	Somerset		124	Unsigned Grid App	9.2	Moy
52	Connected	5.94	Tonroe		125	Unsigned Grid App	1.5	Moy
53	Connected	3.96	Tralee		126	In Planning	13.2	Lisaghmore Main
54	Connected	5.1	Tralee		127	Unsigned Grid App	0.29	Corderry
55	Connected	15	Tralee		128	Unsigned Grid App	32.5	Arklow
56	Connected	6.8	Tralee		129	In Planning	45	Lisaghmore Main
57	Connected	1.65	Trien		130	Unsigned Grid App	1.6	Corderry
58	Connected	2.64	Trien		131	Unsigned Grid App	45	Bellacorick
59	Connected	5	Trillick		132	Unsigned Grid App	12	Doon
60	Connected	4.8	Trillick		133	In Planning	18	Strabane Main
61	Connected	12.6	Tullabrack		134	In Planning	24.5	Ballymena Main
62	Connected	11.9	Wexford		135	Unsigned Grid App	4.25	Cath_Fall
63	Connected	5	Ballymena Main		136	Unsigned Grid App	30	Bellacorick
64	Connected	5	Coleraine Main		137	Unsigned Grid App	44	Bellacorick
65	Connected	5	Larne Main		138	Unsigned Grid App	52	Bellacorick
66	Connected	5	Omagh Main		139	Unsigned Grid App	30	Bellacorick
67	Connected	5	Enniskillen		140	In Planning	20	Ballymena Main

Table A7.7.1

2020 Wind Farm Developments to meet Portfolio 1

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
			Main					
68	Connected	5	Strabane Main		141	Unsigned Grid App	1.7	Trien
69	Connected	13.2	Omagh Main		142	Unsigned Grid App	4.25	Dunmanway
70	Connected	26	Limavady Main		143	Unsigned Grid App	6.5	Dunmanway
71	Connected	22.75	Enniskillen Main		144	Unsigned Grid App	5	Dunmanway
72	Connected	19.5	Omagh Main		145	Contracted	15	Coleraine Main
73	Contracted	11.7	Omagh Main		146	Connected	13.5	Enniskillen Main

Table A7.7.2

Additional 2020 Wind Farm Developments to meet Portfolios 2, 3, 4

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
147	Unsigned Grid App	18	Macroom		215	Unsigned Grid App	11.05	Sligo
148	Unsigned Grid App	4.25	Tralee		216	Unsigned Grid App	33	Thurles
149	Unsigned Grid App	82	Cath_Fall		217	Unsigned Grid App	12	Letterkenny
150	Unsigned Grid App	8	Macroom		218	Unsigned Grid App	12	Tralee
151	Unsigned Grid App	18	Ballycadden		219	Unsigned Grid App	2.3	Butlerstown
152	Unsigned Grid App	3.5	Sorne Hill		220	Unsigned Grid App	16	Trien
153	Unsigned Grid App	0.4	Trillick		221	Unsigned Grid App	2	Ballylickey
154	Unsigned Grid App	1.7	Moy		222	Unsigned Grid App	2.55	Richmond
155	Unsigned Grid App	26.7	Corderry		223	Unsigned Grid App	1.7	Knockeragh
156	Unsigned Grid App	4.5	Trien		224	Unsigned Grid App	3	Trien
157	Unsigned Grid App	60	Coomagearlagh y		225	In Planning	18	Omagh Main
158	Unsigned Grid App	2.1	Bellacorick		226	In Planning	12	Omagh Main
159	Unsigned Grid App	14	Bellacorick		227	Unsigned Grid App	10	Dunmanway
160	Unsigned Grid App	87	Glenlara		228	Unsigned Grid App	4	Crane
161	Unsigned Grid App	5	Macroom		229	In Planning	12	Omagh Main
162	Unsigned Grid App	1.7	Tralee		230	Unsigned Grid App	4.5	Sligo
163	Unsigned Grid App	7.5	Rathkeale		231	Unsigned Grid App	5.1	Tullabrack
164	Unsigned Grid App	3.9	Nenagh		232	In Planning	22	Enniskillen Main
165	Unsigned Grid App	18	Moy		233	Unsigned Grid App	24	Galway
166	In Planning	22	Omagh Main		234	Unsigned Grid App	4	Thurles
167	Unsigned Grid App	20.5	Coomagearlagh y		235	Unsigned Grid App	17	Ballylickey
168	Unsigned Grid App	18	Coomagearlagh y		236	Unsigned Grid App	10	Charleville

Table A7.7.2

Additional 2020 Wind Farm Developments to meet Portfolios 2, 3, 4

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
169	Unsigned Grid App	8.4	Ballylickey		237	Unsigned Grid App	2.5	Charleville
170	Unsigned Grid App	30	Tawnaghmore		238	Unsigned Grid App	6	Binbane
171	Unsigned Grid App	2	Sorne Hill		239	Unsigned Grid App	3.4	Crane
172	Unsigned Grid App	2.55	Dalton		240	Unsigned Grid App	9.2	Sorne Hill
173	Unsigned Grid App	60	Dunmanway		241	Unsigned Grid App	2.5	Rathkeale
174	Unsigned Grid App	46	Trien		242	Unsigned Grid App	18	Coomagearlaghy
175	Unsigned Grid App	1.7	Carlow		243	In Planning	21	Ballymena Main
176	In Planning	18.4	Omagh Main		244	Unsigned Grid App	15	Trien
177	In Planning	44	Omagh Main		245	Unsigned Grid App	20	Tralee
178	Unsigned Grid App	5.82	Ratrussan		246	Unsigned Grid App	8.75	Macroom
179	Unsigned Grid App	14	Galway		247	Unsigned Grid App	8.75	Kilkenny
180	Unsigned Grid App	4.4	Galway		248	Unsigned Grid App	22.5	Galway
181	Unsigned Grid App	24	Ballydine		249	Unsigned Grid App	33	Thurles
182	Unsigned Grid App	13.8	Glenlara		250	Unsigned Grid App	8.5	Coomagearlaghy
183	In Planning	27	Lisaghmore Main		251	Unsigned Grid App	30	Clashavoon
184	Unsigned Grid App	46	Trien		252	Unsigned Grid App	4	Thurles
185	Unsigned Grid App	28	Moy		253	Unsigned Grid App	10.2	Tralee
186	Unsigned Grid App	2	Thurles		254	Unsigned Grid App	0.85	Tralee
187	Unsigned Grid App	4	Thurles		255	Unsigned Grid App	90	Nenagh
188	Unsigned Grid App	4	Thurles		256	Unsigned Grid App	5	Carlow
189	Unsigned Grid App	34.85	Knockeragh		257	Unsigned Grid App	4.25	Sorne Hill
190	Unsigned Grid App	42.5	Nenagh		258	Unsigned Grid App	5	Trien
191	Unsigned Grid App	4.25	Sligo		259	Unsigned Grid App	3.2	Letterkenny

Table A7.7.2

Additional 2020 Wind Farm Developments to meet Portfolios 2, 3, 4

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
192	Unsigned Grid App	7.43	Castlebar		260	Unsigned Grid App	1.9	Binbane
193	Unsigned Grid App	3.05	Dunmanway		261	Unsigned Grid App	4.25	Dunmanway
194	Unsigned Grid App	26.25	Moy		262	In Planning	16.5	Omagh Main
195	In Planning	9	Omagh Main		263	In Planning	12	Omagh Main
196	Unsigned Grid App	3.3	Crane		264	In Planning	27	Omagh Main
197	Unsigned Grid App	16.1	Crane		265	In Planning	10.5	Creagh
198	Unsigned Grid App	20	Crane		266	Unsigned Grid App	4.25	Galway
199	Unsigned Grid App	2	Crane		267	In Planning	18	Omagh Main
200	Unsigned Grid App	5	Dungarvan		268	Unsigned Grid App	1.4	Sorne Hill
201	Unsigned Grid App	4.5	Tullabrack		269	Unsigned Grid App	0.3	Sorne Hill
202	Unsigned Grid App	10	Tralee		270	Unsigned Grid App	30	Dungarvan
203	Unsigned Grid App	2.55	Tralee		271	Unsigned Grid App	3.4	Cath_Fall
204	Unsigned Grid App	46	Trien		272	Unsigned Grid App	6.5	Sorne Hill
205	Unsigned Grid App	8.5	Castlebar		273	In Planning	42	Omagh Main
206	Unsigned Grid App	14.8	Crane		274	Unsigned Grid App	3.4	Castlebar
207	Unsigned Grid App	60	Galway		275	Unsigned Grid App	2.55	Castlebar
208	Unsigned Grid App	0.85	Somerset		276	Unsigned Grid App	3.4	Castlebar
209	Unsigned Grid App	4.5	Corderry		277	Unsigned Grid App	6	Trien
210	Unsigned Grid App	14	Tralee		278	Unsigned Grid App	2	Thurles
211	Unsigned Grid App	4.25	Waterford		279	In Planning	2.5	Ballymena Main
212	Unsigned Grid App	10	Macroom		280	In Planning	16	Dungannon Main
213	Unsigned Grid App	2.6	Crane		281	Unsigned Grid App	26	Letterkenny
214	Unsigned Grid App	4.5	Arklow		282	Unsigned Grid App	21	Carlow

Table A7.7.3

Additional 2020 Wind Farm Developments to meet Portfolio 5

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	lled MW	110kV Node
283	Unsigned Grid App	8.75	Kilkenny		338	Unsigned Grid App	4	Crane
284	Unsigned Grid App	15	Rathkeale		339	Unsigned Grid App	30	Lisdrum
285	Unsigned Grid App	4	Thurles		340	In Planning	28	Omagh Main
286	Unsigned Grid App	4	Trien		341	Unsigned Grid App	0.85	Tipperary
287	In Planning	36.8	Ballymena Main		342	Unsigned Grid App	2.5	Charleville
288	Unsigned Grid App	2.3	Drybridge		343	Unsigned Grid App	55	Lisheen
289	Unsigned Grid App	3	Drybridge		344	Unsigned Grid App	7.65	Sligo
290	Unsigned Grid App	2.5	Rathkeale		345	Unsigned Grid App	3.2	Binbane
291	Unsigned Grid App	2.5	Rathkeale		346	Unsigned Grid App	0.5	Cath_Fall
292	Unsigned Grid App	3	Sligo		347	Unsigned Grid App	29.75	Agannygal
293	Unsigned Grid App	62.5	Cahir		348	Unsigned Grid App	24	Ikerrin
294	Unsigned Grid App	3	Carrick On Shannon		349	Unsigned Grid App	2.55	Nenagh
295	Unsigned Grid App	5	Rathkeale		350	Unsigned Grid App	36	Cullenagh
296	Unsigned Grid App	2.55	Binbane		351	Unsigned Grid App	3	Ennis
297	Unsigned Grid App	2.55	Ikerrin		352	Unsigned Grid App	9	Ennis
298	Unsigned Grid App	32.98	Ennis		353	Unsigned Grid App	5	Charleville
299	Unsigned Grid App	9.7	Ennis		354	Unsigned Grid App	9	Corderry
300	In Planning	24	Omagh Main		355	In Planning	10	Omagh Main
301	Unsigned Grid App	6	Mallow		356	In Planning	14	Strabane Main
302	Unsigned Grid App	5	Ennis		357	In Planning	30	Dungannon Main
303	Unsigned Grid App	18	Glenlara		358	Unsigned Grid App	4.25	Athlone
304	Unsigned Grid App	4.5	Lanesboro		359	Unsigned Grid App	4.5	Mullingar
305	Unsigned Grid App	5	Knockeragh		237	Unsigned Grid App	2.5	Charleville

Table A7.7.3

Additional 2020 Wind Farm Developments to meet Portfolio 5

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	lled MW	110kV Node
306	In Planning	16	Omagh Main		360	Unsigned Grid App	12.5	Dundalk
307	Unsigned Grid App	4	Trillick		361	Unsigned Grid App	0.85	Ikerrin
308	Unsigned Grid App	19.4	Dungarvan		362	Unsigned Grid App	4	Knockeragh
309	Unsigned Grid App	57	Clashavoon		363	Unsigned Grid App	0.5	Knockeragh
310	In Planning	19.5	Omagh Main		364	Unsigned Grid App	79.2	Thornsberry
311	Unsigned Grid App	3.9	Ikerrin		365	Unsigned Grid App	3	Ardnacrusha
312	Unsigned Grid App	18	Rathkeale		366	Unsigned Grid App	22	Tipperary
313	Unsigned Grid App	15	Meath Hill		367	In Planning	15.75	Enniskillen Main
314	Unsigned Grid App	18	Midleton		368	Unsigned Grid App	29.1	Charleville
315	Unsigned Grid App	31.525	Corderry		369	Unsigned Grid App	29.9	Moy
316	Unsigned Grid App	10	Tralee		370	Unsigned Grid App	30	Ikerrin
317	Unsigned Grid App	18.5	Glenlara		371	Unsigned Grid App	9	Thurles
318	Unsigned Grid App	5.25	Kilkenny		372	Unsigned Grid App	48	Fass East
319	Unsigned Grid App	105	Galway		373	In Planning	17.5	Enniskillen Main
320	Unsigned Grid App	6.1	Tipperary		374	Unsigned Grid App	0.85	Dundalk
321	Unsigned Grid App	8	Crane		375	In Planning	30	Enniskillen Main
322	Unsigned Grid App	0.5	Crane		376	Unsigned Grid App	18	Knockeragh
323	Unsigned Grid App	6.5	Glenlara		377	Unsigned Grid App	21	Doon
324	Unsigned Grid App	00.8	Galway		378	Unsigned Grid App	9	Oughteragh
325	Unsigned Grid App	.85	Mallow		379	Unsigned Grid App	0.5	Meath Hill
326	In Planning	0	Enniskillen Main		380	Unsigned Grid App	2.55	Ikerrin
327	Unsigned Grid App	.25	Carrick On Shannon		381	Projected	13.86	Slivermines
328	Unsigned Grid App	.7	Midleton		382	Projected	41.58	Ballydine

Table A7.7.3

Additional 2020 Wind Farm Developments to meet Portfolio 5

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	lled MW	110kV Node
329	In Planning	6	Omagh Main		383	Projected	13.86	Ballydine
330	Unsigned Grid App	.99	Knockeragh		384	Projected	13.86	Moy
331	Unsigned Grid App	4	Knockeragh		385	Projected	13.86	Sorne Hill
332	Unsigned Grid App	6	Mallow		386	Projected	13.86	Kiltoy
333	Unsigned Grid App	4	Ennis		387	Projected	13.86	Ballynahinch Main
334	Unsigned Grid App	.7	Midleton		388	Projected	41.58	Sorne Hill
335	Unsigned Grid App	.5	Carlow		389	Projected	13.86	Bellacorrick
336	In Planning	9	Omagh Main		390	Projected	41.58	Binbane
337	In Planning	7	Strabane Main		391	Projected	55.44	Oughtragh
					392	Projected	13.86	Sorne Hill

Table A7.7.4

Additional 2020 Wind Farm Developments to meet Portfolio 6

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
393	Projected	124.74	Clunghill		432	Projected	27.72	Ardnacrusha
394	Projected	13.86	Dunmanway		433	Projected	13.86	Kilkenny
395	Projected	27.72	Binbane		434	Projected	97.02	Limavady Main
396	Projected	13.86	Golagh		435	Projected	13.86	Ballylicky
397	Projected	55.44	Slivermines		436	Projected	13.86	Ikerrin
398	Projected	41.58	Buncranna		437	Projected	13.86	Newmarket
399	Projected	55.44	Buncranna		438	Projected	55.44	Clunghill
400	Projected	55.44	Stratford		439	Projected	13.86	Lisaghmore Main
401	Projected	27.72	Cahir		440	Projected	27.72	Lisaghmore Main
402	Projected	13.86	Donegall Main		441	Projected	13.86	Cahir
403	Projected	13.86	Ballylicky		442	Projected	13.86	Anner
404	Projected	27.72	Ballylicky		443	Projected	27.72	Carlow

Table A7.7.4

Additional 2020 Wind Farm Developments to meet Portfolio 6

Ref	Status	Installed Capacity MW	110kV Node		Ref	Status	Installed Capacity MW	110kV Node
405	Projected	27.72	Corraclassy		444	Projected	27.72	Cahir
406	Projected	13.86	Anner		445	Projected	13.86	Ballylicky
407	Projected	13.86	Kiltoy		446	Projected	13.86	Dunmanway
408	Projected	41.58	Castlebar		447	Projected	13.86	Ballylicky
409	Projected	13.86	Slivermines		448	Projected	13.86	Dunmanway
410	Projected	13.86	Oughtragh		449	Projected	41.58	Cahir
411	Projected	27.72	Arigna		450	Projected	13.86	Ballylicky
412	Projected	13.86	Sorne Hill		451	Projected	27.72	Ardnacrusha
413	Projected	13.86	Oughtragh		452	Projected	13.86	Crane 110kv
414	Projected	27.72	Binbane		453	Projected	27.72	Tipperary
415	Projected	83.16	Oughtragh		454	Projected	13.86	Tipperary
416	Projected	13.86	Buncranna		455	Projected	41.58	Corderry
417	Projected	55.44	Shelton Abbey		456	Projected	13.86	Shelton Abbey
418	Projected	27.72	Dunmanway		457	Projected	27.72	Wexford
419	Projected	13.86	Trillick		458	Projected	13.86	Corderry
420	Projected	13.86	Castlebar		459	Projected	13.86	Thurles
421	Projected	27.72	Bellacorrick		460	Projected	27.72	Corderry
422	Projected	27.72	Castlebar		461	Projected	13.86	Wexford
423	Projected	27.72	Cahir		462	Projected	13.86	Shankill
424	Projected	13.86	Tawnaghmore		463	Projected	27.72	Clunghill
425	Projected	13.86	Kiltoy		464	Projected	13.86	Cliff
426	Projected	27.72	Ballylicky		465	Projected	13.86	Limavady Main
427	Projected	13.86	Tipperary		466	Projected	13.86	Dungarvan
428	Projected	41.58	Stratford		467	Projected	27.72	Dungarvan
429	Projected	13.86	Sorne Hill		468	Projected	13.86	Butlerstown
430	Projected	13.86	Sorne Hill		469	Projected	13.86	Sligo
431	Projected	13.86	Kiltoy		470	Projected	13.86	Shankill
					471	Projected	13.86	Tralee

Table A7.7.5

Wind Farm Developments Ranked by Levelised Cost

Encompassing Portfolios 1 to 6

Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected
€0.04	Existing		€0.05	Existing		€0.05	Projected
€0.04	Existing		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.04	Projected		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Existing		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected

Table A7.7.5 Continued

Wind Farm Developments Ranked by Levelised Cost

Encompassing Portfolios 1 to 6

Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Existing		€0.05	Projected		€0.05	Projected
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.05	Projected		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing

Table A7.7.5 Continued

Wind Farm Developments Ranked by Levelised Cost

Encompassing Portfolios 1 to 6

Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.06	Existing		€0.06	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.06	Projected		€0.07	Existing		€0.08	Existing
€0.06	Projected		€0.07	Existing		€0.08	Existing
€0.06	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing

Table A7.7.5 Continued

Wind Farm Developments Ranked by Levelised Cost

Encompassing Portfolios 1 to 6

Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.08	Existing
€0.07	Existing		€0.07	Existing		€0.09	Existing
€0.07	Existing		€0.07	Existing		€0.09	Existing
€0.07	Existing		€0.07	Existing		€0.09	Existing
€0.07	Existing		€0.07	Existing		€0.09	Existing
€0.07	Existing		€0.07	Existing		€0.09	Existing
€0.07	Existing		€0.07	Projected		€0.09	Existing
€0.07	Existing		€0.07	Existing		€0.09	Existing
€0.09	Existing		€0.10	Existing		€0.10	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing
€0.09	Existing		€0.10	Existing		€0.11	Existing

Table A7.7.5 Continued

Wind Farm Developments Ranked by Levelised Cost

Encompassing Portfolios 1 to 6

Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected		Levelised Cost €/kWh	Existing or Projected
€0.11	Existing						
€0.12	Existing						
€0.12	Existing						
€0.12	Existing						
€0.12	Existing						
€0.12	Existing						
€0.13	Existing						
€0.13	Existing						
€0.13	Existing						
€0.13	Existing						
€0.13	Existing						
€0.13	Existing						
€0.14	Existing						
€0.14	Existing						
€0.14	Existing						
€0.15	Existing						
€0.15	Existing						
€0.15	Existing						
€0.15	Existing						
€0.16	Existing						
€0.16	Existing						
€0.17	Existing						
€0.24	Existing						
€0.31	Existing						
€0.32	Existing						
€0.41	Existing						
€0.47	Existing						

Appendix 8
Wave Energy Resource

A8.1 Introduction

As with other renewable resources, wave energy is evaluated in terms of its theoretical, technical, practicable and accessible resource levels. This was initially carried out for the Republic in Ref. (17). It has been confirmed Ref. (31) that the resource for Northern Ireland is not great, and in reality, attention should focus on the west coast of the Republic. A key factor is the performance credibility of the type and disposition of converter that is used to convert theoretical hydrodynamic power levels to achievable electrical power at the technical resource stage. During compilation of Ref. (17) the technical resource was estimated using data published for the Pelamis 750 by its developer, Ocean Power Delivery (OPD). The current model on offer is the Pelamis PIB and a significant change in machine spacing to 350m has been made to avoid any potential for collision between moored machines. This has the effect of reducing the number of converters per km but it is stated that capacity factor is improved as the 180m long converters now contain four power generation elements of smaller individual capacity than the three units fitted to the prototype, the overall capacity of each converter remains the same at 750kWe. Revised calculations were therefore necessary for the Technical, Practicable and Accessible resources but the methods follow those of Ref. (17). Revised calculations were also made for Wave Dragon where it was found that its larger projected rating gave this converter an advantage. These are reported in detail below.

The **Theoretical** energy resource is the gross energy content of the wave resource within a rectangular block of ocean that encompasses the island of Ireland. Raw wave power and energy are measured in terms of hydrodynamic (not electrical) kW/m of wave front and kWh respectively.

The hourly theoretical power resource at each point on a grid of 744 points spaced at 0.25^{o} (latitude and longitude) apart was calculated from data provided by the Danish Meteorological Institute using an internationally recognised Wave Model (WAM). This gave values of Hs (Significant Wave Height m) and Tz (Zero Crossing Wave Period, secs) at the above grid points. The distribution of these values across the area of interest was correlated with contemporaneously measured data recorded at five buoys operated jointly by the Irish Marine Institute and the UK and Irish Meterological Services. In general the model data was smoothly reduced somewhat to match the buoy data adjacent to the specific buoy locations. The duration of the hourly records covered the period 2001-4. Inevitably some gaps in buoy data occurred but all records were scrutinised and dubious or null values were excluded. The degree of correlation between WAM results and the buoy measurements varied from year to year and buoy to buoy. Correlation of Hs was significantly better than for Tz throughout. As the instantaneous hydrodynamic power flux is calculated from the formula

$$p = 0.55\, H_s^2 Tz$$

the effect of differences in Tz on the power level is less marked than differences in Hs would be. It is felt that directionality, which was projected by WAM but was not measured at the buoys, may have some influence on the discrepancies noted. The mean annual hydrodynamic theoretical power flux resource was then plotted over the area of interest and could be converted to energy resource by summing the number of hours per year at which particular power levels were experienced. Both were plotted as contours.

A8.2 The Mean Annual Technical Energy Resource (Wave Dragon)

A8.2.1 Introduction

The next stage was conversion of the **Theoretical Resource** to **Technical Resource** which is given in electrical terms and reflects the conversion potential of the particular reference converter chosen. In “Accessible Wave Energy Resource Atlas – Ireland 2005” the Pelamis P1 (750kWe) machine was used as reference converter but for the purpose of this report the larger projected 7MWe rated Wave Dragon machine is used. With the spacings now projected by the developers a cordon of Wave Dragons would have a rating of 14MWe/km (500m spacing) while the figure for Pelamis would be 5.7MWe/km (350m spacing x 3 layer). (Later versions of Pelamis are expected to have increased capacity).

Depending on the types of converter configuration envisaged different levels of Technical resource may be derived from the Theoretical resource. Each converter has its own unique bivariate conversion or scatter table that gives the electrical power output for combinations of Hs and Tz. This provides a three dimensional surface, analogous to the two dimensional power characteristic of a wind turbine. By summing the number of occurrences of these joint values of Hs and Tz and their corresponding electrical power output values the mean power flux for a given period (day, season, year) can be estimated and plotted. Depending on spacing etc. each type of converter will “map out” its own particular set of contours of power flux and energy for the region of interest i.e. waters available for Ireland.

The annual technical energy resource is estimated by averaging the annual electrical power that would arise at each node point when the sequence of hourly Hs, Tz pairs are inserted in the converter power table, working within the spacing, depth ranges and cabling limits specified for the particular converters. The power levels are summed to obtain the annual average electrical energy resource level.

Thus in the cases of both the theoretical and technical resource the averages have been obtained by the summation of the thousands of real individual hourly values rather than via the creation of an arbitrary resource level from a notional annual “average” Hs and an “average” Tz.

Evaluation of the technical resource requires that the theoretical resource be converted to its equivalent technical value via use of converter-specific scatter diagrams or bivariate distributions linking electrical output to the occurrence of particular significant wave heights (Hs) and zero crossing periods (Tz) from the statistical records that are available at each grid point and reference point on the 20m contour. Thus the occurrence of electrical power levels at these grid and reference points can be determined, leading to corresponding contours of power level across the area of interest. Figs. (01, 06). This highlights the fact that different power converter types will have different outputs depending on their particular response to the input data (Hs and Tz). The output values are calculated hour by hour and summed over time to get the mean levels.

At this point it is assumed that there is no restriction on laying out converter cordons in the sea so that the technical resource can be evaluated. Clearly the scatter tables provided by the developers must be considered to be indicative only and based on the limited duration of information available. (No warranty is expressed or implied that they will be found to represent specific ongoing conditions at the respective points or elsewhere).

A8.2.2 Converter Spacing

Relatively little work has been published on the interaction between groups of wave converters and the extent to which energy continues to be available in the lee of a cordon of converters. For the purposes of this report it is assumed that a single linear cordon of converters formation, spaced at distances recommended by the respective developers can be used to estimate the electrical power and energy resource. (One developer whose converter spacing is quite generous (1km) suggests that a second cordon might be located 30-35km leeward of the outer cordon with a reasonable prospect of collecting additional power. This option has not been considered further in the current study but suggests an area for active research and quite possibly an enhanced resource).

The spacings suggested by the reference converter developer are

Wave Dragon 1 @ 7 MWe machine per 500m to give 14MWe capacity per km.

This configuration of machines leads to the ranges of energy recovery and mean power levels shown in the figures. Essentially the different converter types may be distinguished by the number of machines allowed per unit length of cordon and the particular scatter diagram of Hs, Tz applicable in each case. Thus the technically available resource **varies with the distribution of the theoretical resource**, **the converter characteristics and the number of such converters per unit length of cordon** that are allowable without mutual interference and degeneration of output.

A8.2.3 Detailed Technical Resource

Estimation of the technical resource requires projection of the electrical power and energy levels that the historical wave regimes would attain if they were allowed to act upon a cordon of real converters or converter groups.

Fig. (A8-1) shows the mean annual technical power output in terms of MWe/km for the Wave Dragon. This is derived by an hourly comparison of the forecast Hs, Tz values with the corresponding values on the power scatter diagram for that converter. It is assumed that electromechanical conversion efficiency for the units is 85%, based on information supplied by the Wave Dragon team, the machines are spaced in a single cordon as described in A8.2.2 above. The figure shows that such a cordon would produce 5.0MWe/km along a line within 75km of the west coast. 4-4.5MWe/km would be obtainable within 25km over large sections of coastline (Mayo, Galway, Kerry and part of Co. Clare).

Table A8.1 summarises the technical power flux levels obtainable using the Wave Dragon cordon at different distances from the coast. The contour lengths are limited to those occurring in the ‘box’ of interest.

Table A8.1

Mean Annual Technical Power Levels Crossing Contours (Wave Dragon)

(a) Ave Contour Level MWe/km	(b) Contour Length km	Ave. Elec. Power at Contour = (a.b. ÷1000) GWe
1	313	0.31
1.5	438	0.656
2	500	1.0
2.5	620	1.55
3	675	2.025
3.5	785	2.747
4	850	3.4
4.5	725	3.26
5.0	375	1.875

Summing the output per km of wave front yields the Mean Annual Technical Energy Resource for Wave Dragon (Fig. A8-6). (It should be noted that in Figs. 01-06 Wave Dragon creates its own contours of power flux and energy based on passing the hindcast wave records at different locations through the Wave Dragon scatter table. A different converter will in general produce a different set of outputs although in the longer term these would be expected to converge towards a best attainable value as the technologies mature). Fig. A8-6 shows that an unrestricted cordon of Wave Dragon converters could produce the following mean energy outputs at different distances offshore. (Table A8.2)

An important feature highlighted here is that a wave converter will usually perform best when operating in waves that match a particular region of its scatter table. Thus Fig. (A8-1) shows a 'high performance' area off the Irish west coast where waves of this type predominate and this converter performs well. Going further offshore into an area of higher waves of longer period results in a reduction in performance of this particular machine.

A disappointing feature is that the implied annual capacity factors are somewhat on the low side. They are not however dissimilar to those experienced during the earlier stages of wind power development and could be expected to improve with refinement in converter tuning and design.

Considering the seasonal power outputs using the reference converter, Figs. (A8-2, 4) show (as is to be expected from the earlier figures) that Spring and Autumn outputs are rather similar. It is notable that the power production regime off the north west coasts is higher in Autumn than in Spring, while the reverse is true off the South West coast. There are no significant differences in power outputs at the south and east coasts. Again (Fig. A8-3) the Winter power output increases significantly (20-30%) over the Autumn figures while the Summer (Fig. A8-5) falls by 55% from 4.5 to 2MWe/km within 25km of the west coast.

Table A8.2

Mean Annual Technical Energy Resource (Wave Dragon)

Contour Level GWhe/km	Nett Contour Length km	Annual Elec. Energy TWhe	Implied Capacity Factor %
8	212.5	1.7	6.5
10	450	4.5	8.15
12	450	5.4	9.78
14	495	6.93	11.4
16	500	8.0	13.04
18	488	8.77	14.67
20	575	11.5	16.3
22	625	13.75	17.93
24	650	15.6	19.57
26	693	19.39	21.2
28	770	21.56	22.83
30	780	23.4	24.46
32	793	25.36	26.1
34	775	26.35	27.22
36	840	30.24	29.36
38	838	31.83	30.98
40	750	30	32.62
42	800	33.6	34.24
44	375	16.5	35.9

The corresponding mean seasonal technical energy resource utilising the Wave Dragon is shown in Figs. (A8-7-10). The Winter levels of the resource (Fig. A8-8) show that 12-14GWhe/km would be obtainable utilising a cordon within 50km of the whole west coast (apart from Donegal and Galway Bays). In Summer this figure drops to 4-5GWhe/km (Fig. A8-10) while in Spring and Autumn Figs. (A8-7, 9) it rises to 8-10GWhe/km.

A8.3 Practicable Mean Annual Energy Resource

A8.3.1 Introduction

Areas associated with wrecks, overfalls, extreme currents where the wave pattern may be distorted and where severe drag or fatigue may occur on downcomers (power cables, anchor, mooring cables) leading to converter damping are deleted.

It is of course arguable that at a future time, if the wave pattern at particular overfall locations has been adequately characterised through prolonged in-situ measurements they will be found to be acceptably predictable (because of the tidal stream influence) or even desirable for particular converter types and will be able to yield unusually high output.

Bearing in mind, however, the probable difficulties of mooring and utilising service vessels under such conditions, these areas are deleted at this point in time.

A8.3.2 Detailed Practicable Resource

The specific deletions made are listed in Table A8.3 and the results of these deletions are shown in Figs. (A8-11, 12) showing distribution of Practicable mean annual power and energy resources. These result in Tables A8.3 and A8.3.

Table A8.3

Deletions made to establish Practicable Resource

- Areas with depth < 50m
- Areas at Overfalls (minor areas easily avoided)
- Areas at Wrecks (minor areas easily avoided)
- Areas further than 100km from coast (defined off baseline of 12 mile limit) as practical economic limit of transmission cabling at scales envisaged
- Areas where surface current exceeds 1.0 knot. In general these are within 50m depth zone or in areas where the average power resource is relatively small (Irish sea, North Channel).

Table A8.4

Mean Practicable Power Levels Crossing Contours

(a) Ave Power Contour Level MWe/km	(b) Nett Contour Length km	Ave. Elec. Power at Contour GWe
1	200	0.1
1.5	400	0.6
2	400	0.8
2.5	538	1.34
3	600	1.8
3.5	713	2.49
4	700	2.8
4.5	595	2.68
5.0	375	1.88

Table A8.5

Mean Annual Practicable Energy Resource (Wave Dragon)

Energy Contour Level GWhe/km	Contour Length km	Annual Elec. Energy TWhe	Implied Capacity Factor %
8	75	0.6	6.5
10	300	3.0	8.15
12	425	5.1	9.78
14	413	5.78	11.42
16	450	7.2	13.04
18	363	6.53	14.67
20	525	10.5	16.30
22	538	11.83	17.93
24	575	13.8	19.57
26	588	15.28	21.2
28	635	17.78	22.83
30	710	21.3	24.46
32	720	23.0	26.1
34	720	24.5	27.22
36	688	24.75	29.36
38	690	26.2	30.98
40	563	22.5	32.62
42	500	21.0	34.24
44	375	16.5	35.9

Thus the effect of reducing available contour lengths to facilitate other users is to reduce the averaged electrical energy per contour somewhat from 14.58TWhe to 12.93TWhe or 11% (derived from Tables A8.7 and A8.5). The equivalent energy figures are considered on Table A8.4.3 derived from Fig. (A8-14).

A8.4 The Accessible Mean Annual Energy Resource

A8.4.1 Introduction

A further set of deletions is made to exclude mineral extraction zones, special fishing areas, navigation lanes, windfarm concessions, fish farms, pipelines and cables, current network capacity limits and notified environmental zones and the average annual energy output associated with these areas. This results in the residual accessible mean annual energy resource.

The distribution of this resource is shown on Figs. (A8-13, 14) and is quantified in tables 7.1(a), 7.2(a). As noted earlier the accessible resource may be further broken down into three segments viz.

- Viable Open Market Segment
- Viable Managed Market Segment
- Non Viable Market Segment

depending on current or projected market conditions and status of technological development.

Although methodology for addressing these issues as a function of market conditions has been developed by ESBI (Ref. 12), it is outside the scope of the present report to discuss these issues in detail. Apart from the nature of the resource, technological improvement and relative capital costs of other renewables and fossil fuels are major determinants in this area.

A8.4.2 Detailed Accessible Resource

Table A8.5 summarises the overall accessible electrical power flow levels obtainable using the Wave Dragon cordon at different distances from the coast. For the purposes of this report the cordon is assumed to be continuous and to lie along the respective contours shown on Fig. A8-13. However it is to be expected that such a cordon would in reality consist of intermittent groups of converters staggered so as to allow maximum sea room for navigation and wave transfer between the groups. In fact in this case there is relatively little difference between the Practicable and Accessible resources as the scale of the deletions made at the accessible stage is rather small. The purpose of the exercise is to highlight potential interface areas rather than to postulate outright arbitrary development restrictions on wave conversion because particular areas have e.g. fishery connotations at present.

Most of the deletions are too close inshore to have a significant effect on the contours of power and energy. Deletions from the lengths of these contours are made where sea bed cables or notional approaches to ports are crossed. Two large fishing areas are shown edged in red on Figs. (A8-13,14). It is assumed that an indicative 50% reduction in contour length is made on passing through these areas. Further deletions might need to be made in respect of established submarine exercise areas. These effects can be noted in the changed nett contour lengths of Table A8.7, relative to Table A8.5.

In calculating these reductions the following are taken into account as detailed on Table A8.6.

Table A8.6

Deletions made to establish Accessible Resource

- Cable + Pipeline corridor Width: 1km per corridor (green on Figs.)
- Shipping Corridor Width: 5km per port corridor (green on Figs.)
- Fishery Blocks: 0.5 x contour length within blocks shown on Figs. A8-13, 14
- Marine Traffic Separation zones: contour length within zone
- Submarine exercise areas not included. (See Admiralty Charts)
- Military Danger Areas (Red on Figs).

Table A8.7

Mean Annual Accessible Energy Resource (Wave Dragon)

Energy Contour Level GWhe/km	Nett Contour Length km	Annual Elec. Energy TWhe	Implied Capacity Factor %
8	45	.36	6.5
10	203	2.03	8.15
12	303	3.63	9.78
14	309	4.32	11.42
16	367	5.87	13.04
18	292	5.25	14.67
20	459	9.18	16.3
22	472	10.38	17.93
24	510	12.24	19.57
26	521	13.5	21.2
28	518	14.5	22.83
30	651	19.5	24.46
32	644	20.6	26.1
34	604	20.54	27.72
36	571	20.55	29.36
38	570	21.66	30.98
40	449	17.96	32.62
42	395	16.6	34.24
44	375	16.5	35.9

The importance of the North West Mayo, and Kerry areas in particular is evident from their proximity to contours where relatively high converter capacity factors are projected as being likely. The North West Donegal area is moderately attractive. Unfortunately electrical network capacity is still relatively weak in those areas although it has been improving as part of a general strengthening of the system and because of the need to cater for planned wind farms.

This should not pose a major problem for small scale/demonstration level wave projects however.

The above analysis has been carried out based on figures available for the performance of Wave Dragon 7MWe and which is not yet available as a full scale converter. There are indications that projected scatter tables for other systems currently under development may give better energy recovery rates but this has still to be demonstrated in full scale.

A8.5 Environmental Issues

It is necessary to recognise that in the final analysis each case for wave power development will be assessed on its merits against established objective criteria wherein the extent of impacts and mitigation measures alike are assessed in reaching decisions. It is important that the collection of relevant baseline information is put in hand so that its absence is not used as an excuse to delay the granting of necessary permissions associated with possible implementation of preliminary wave conversion demonstration projects.

A8.6 Commercial Considerations

A standardised method of commercial analysis based on that used by the Commission for Energy Regulation in determining the cost/kW for the ‘Best New Entrant’ to the electricity market (usually a 400MWe combined cycle gas turbine) has been developed in Ref. (17). The model is available to potential users on the SEI website.

There is relatively little firm information publicly available on the projected costs of specific full size multi megawatt wavepower projects.

The figures obtained are actually better than were obtained during early development of wind turbines. With improved capacity factors and quantity production of converters there is every expectation that corresponding reductions would go some way toward offsetting other uncertainties in cost estimation.

The improvements primarily relate to economy of scale and improved capacity factor. Clearly many of the assumptions used may be further debated and remain to be proven in the hard world of offshore engineering but there are reasonable grounds for believing that wavepower, in the context of the Irish wave climate, is closing the gap on other renewables such as offshore windpower.

The 1400MWe of capacity required for Portfolio No. 6 is made up by eleven wave farms tentatively located as shown on Fig. A8-15 with capacity, connection and cost details as per Table A8.8. The levelised costs and capacities are ranked on the levelised cost curve of Fig. A8-16.

A8.7 Data Provided to Other Work Streams

Table A8.8

Projected Links between Wave Farms and 110kV Stations

Name	Installed Capacity MW	110kV Station	Levelised Cost €cent/kWh
North West A	154	Tawnaghmore	€0.11
North West B	140	Bellacorrick	€0.10
North West C	154	Castlebar	€0.11
West A	112	Dalton	€0.11
West B	112	Cloon	€0.11
West C	112	Galway	€0.11
West D	98	Ennis	€0.15
South West A	140	Tralee	€0.11
South West B	126	Oughtragh	€0.11
South West C	140	Knockearagh	€0.11
South West D	112	Ballylicky	€0.11

A8.8 Conclusions

(1) The methodology developed during production of Ref. (17) has been used to estimate the accessible wave energy resource on the Irish West Coast, utilising the floating Wave Dragon as the reference converter in this instance.

(2) Prime sites have been identified off the Mayo, Galway and Kerry coasts and the estimated spread of converters necessary to meet the portfolio 6 plant requirements for 2020 identified.

(3) The distribution of converters is shown on the accompanying diagram (Figure A8-15). It is arranged so that the power loading on any of the target 110kV stations does not exceed circa 150MW as summarised in Table A8.8.

(4) Although the data, including costs, can only be regarded as preliminary at this stage, there is a very close cost correlation between the sites chosen, apart from West 'D'. Levelised costs for the other ten sites are banded between €0.104 and €0.112/kWhe. In reality the detailed conditions of each site would be expected to widen this band but this outcome is a positive starting point, as it indicates the presence of a significant resource at a relatively constant cost.

A8.9 Recommendations

The configuration of converters discussed in A8.7 above should be carried forward to form part of the relevant portfolios.

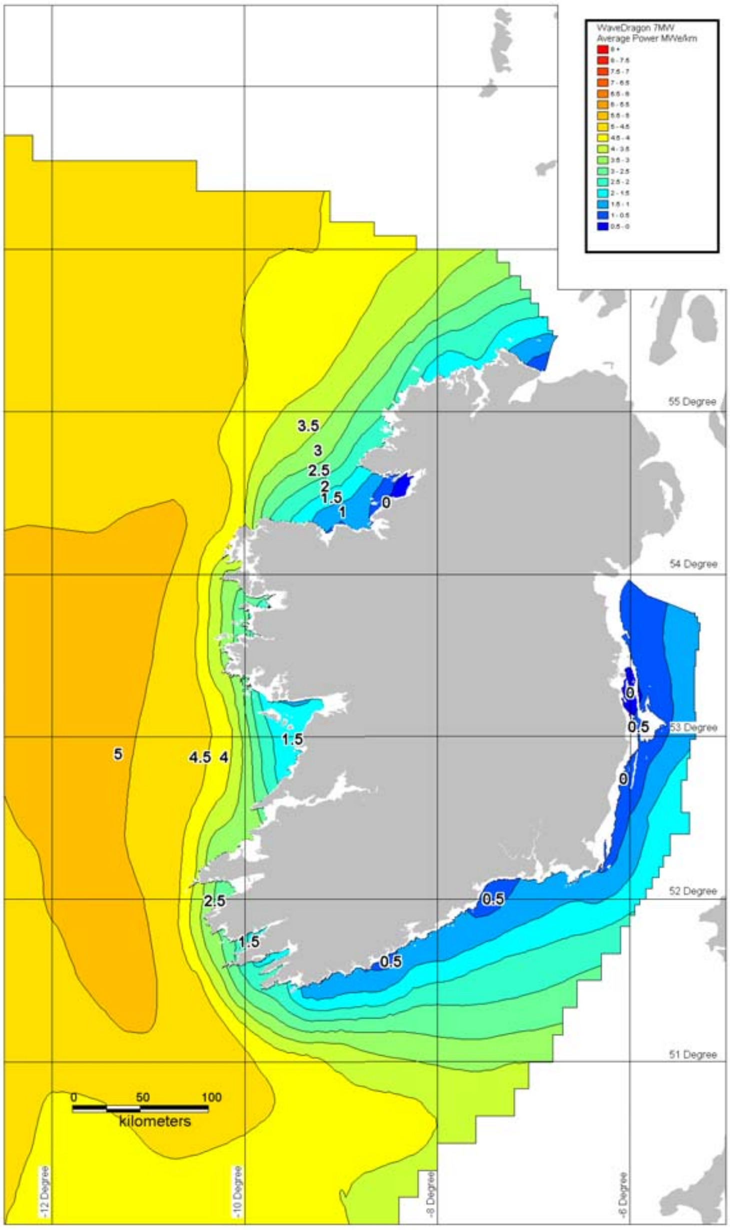


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Fig. A8-1 Mean Annual Technical Power Resource (WaveDragon) MWe/km

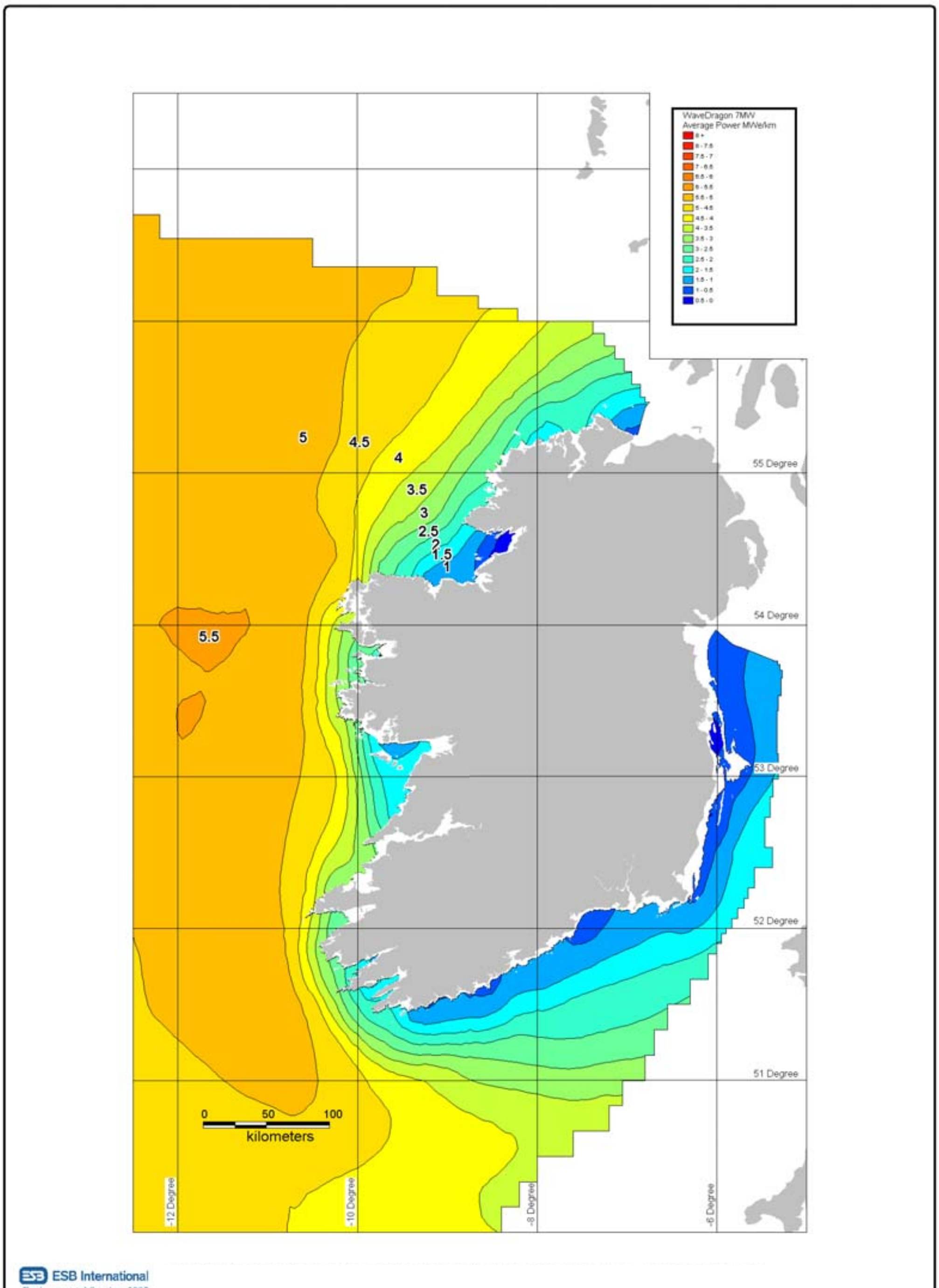

Fig. A8-2 Mean Seasonal Technical Power Resource (WaveDragon) - Autumn MWe/km

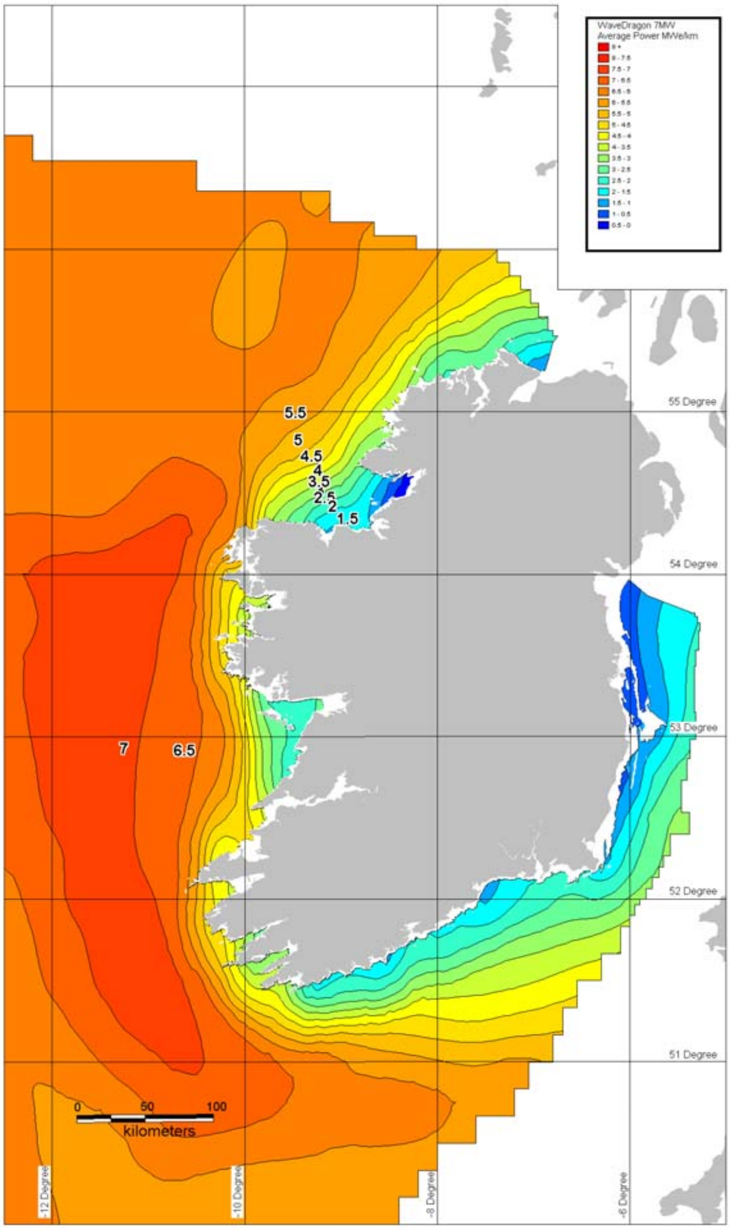

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Fig. A8-3 Mean Seasonal Technical Power Resource (WaveDragon) - Winter MWe/km

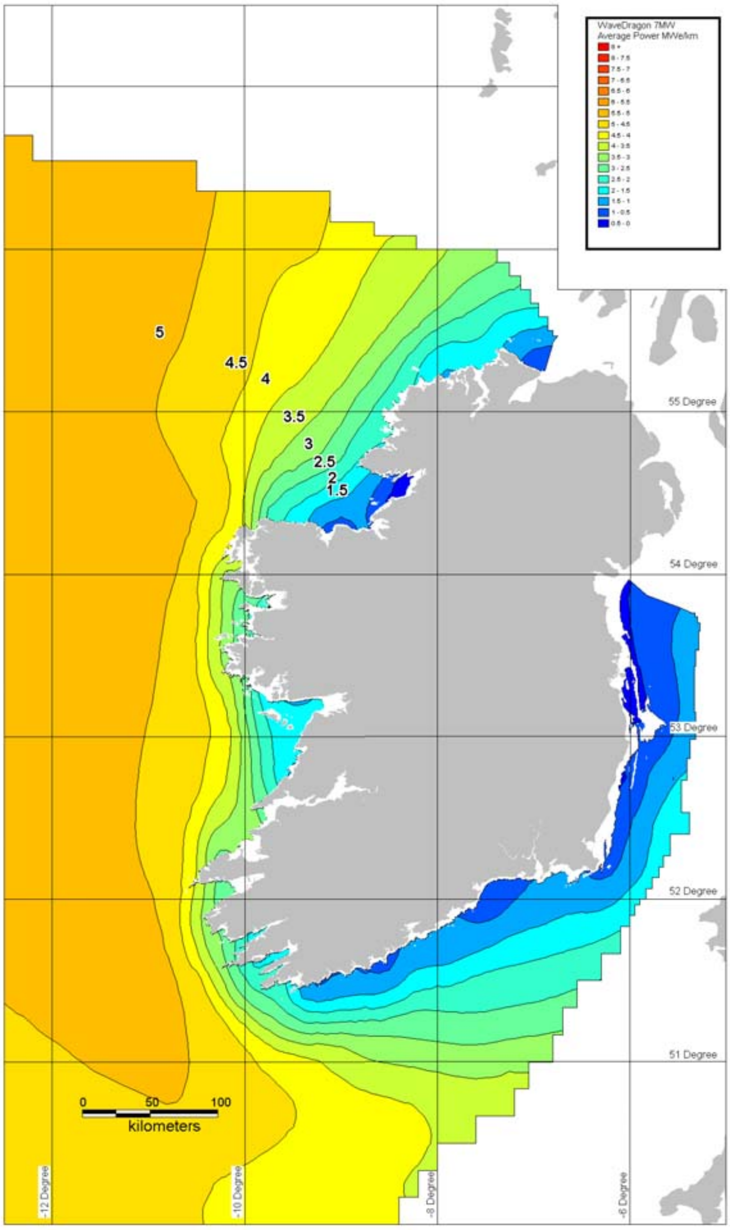

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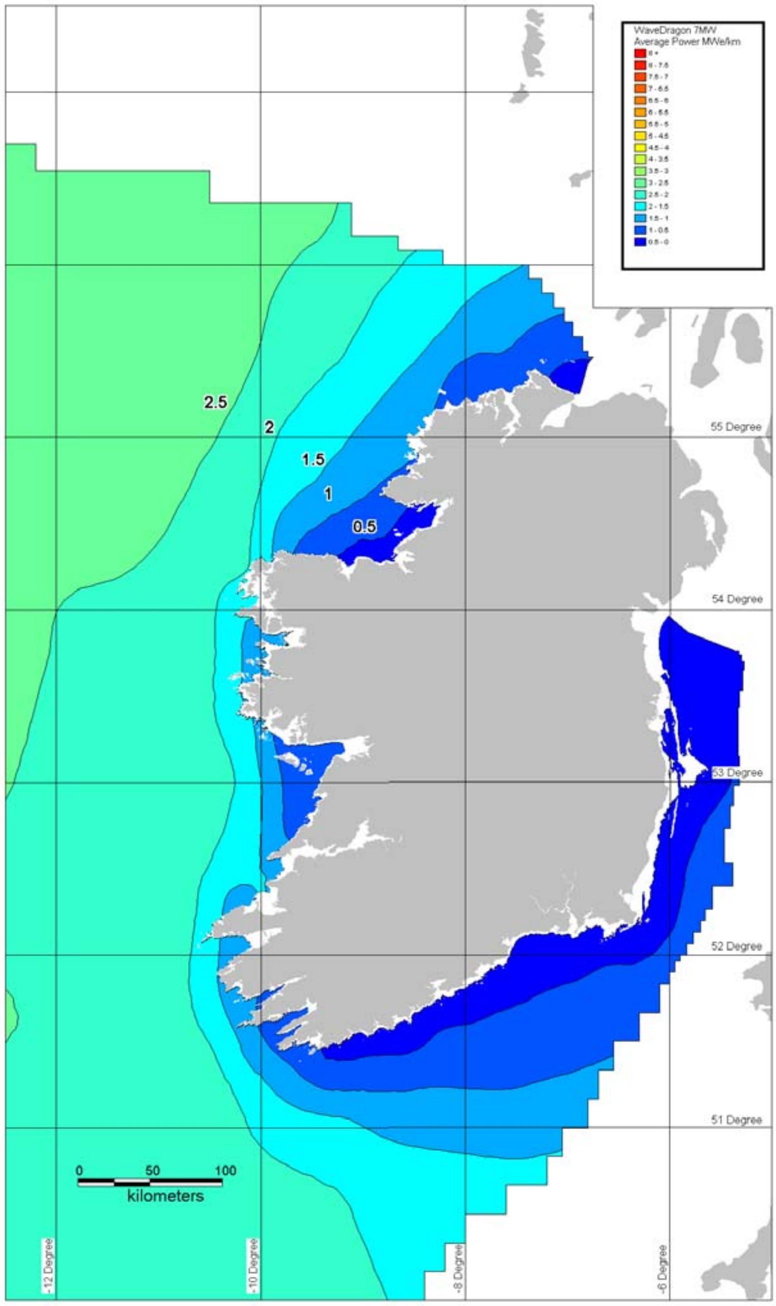
Fig. A8-4 Mean Seasonal Technical Power Resource (WaveDragon) - Spring MWe/km



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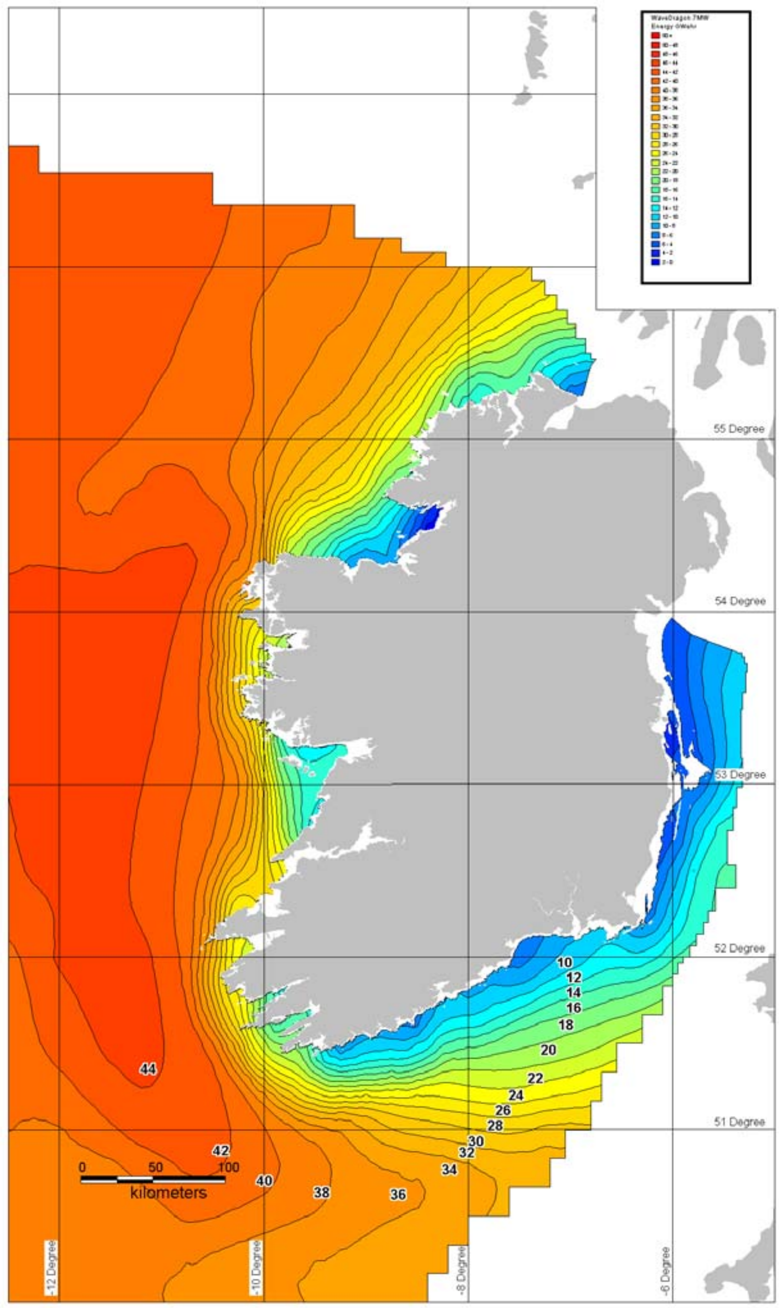
Environmental Services 2005

Fig. A8-5 Mean Seasonal Technical Power Resource (WaveDragon) - Summer MWe/km



ESB International
Environmental Services 2005

Fig. A8-6 Mean Annual Technical Energy Resource (WaveDragon) GWhe/km

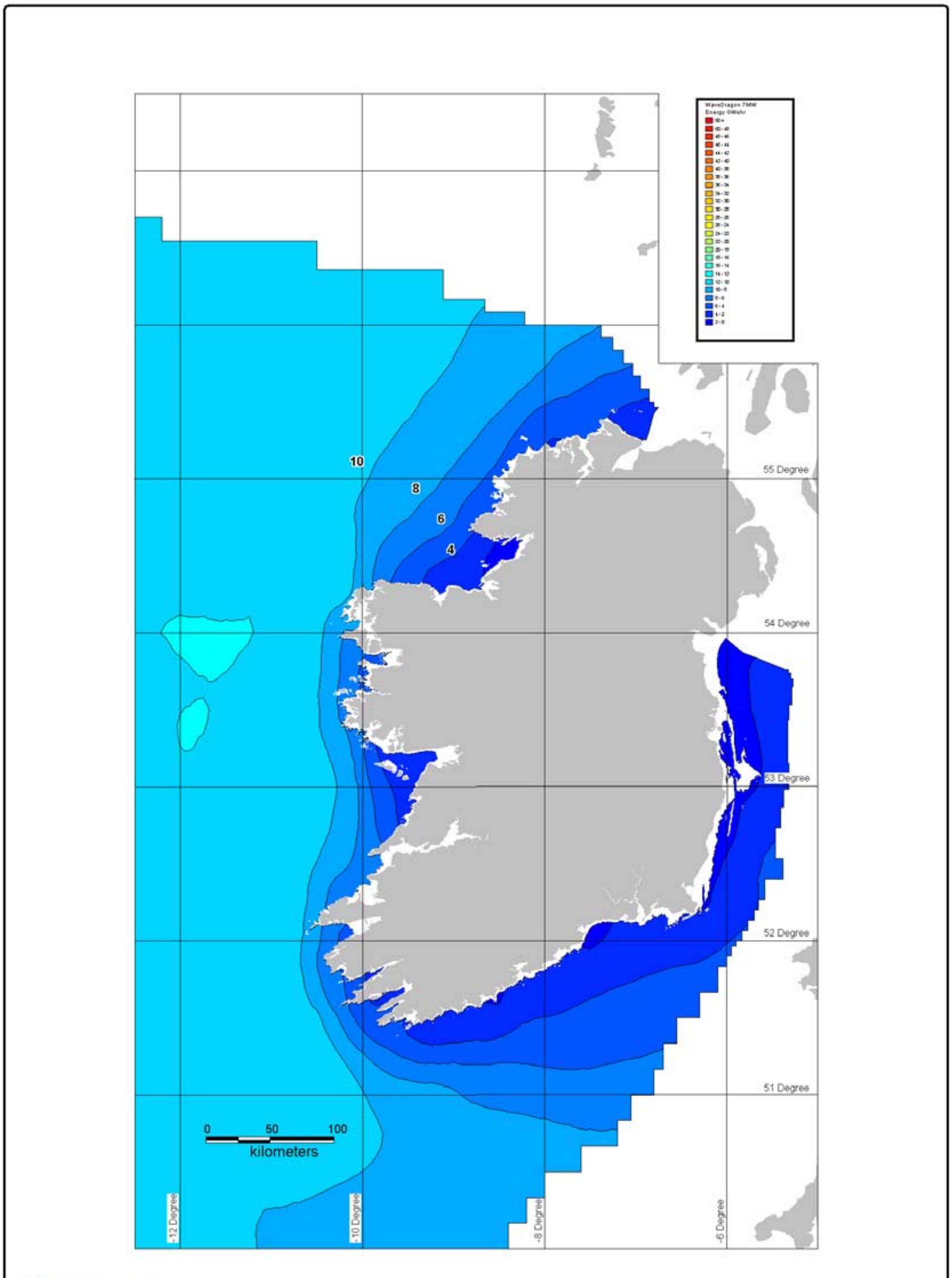
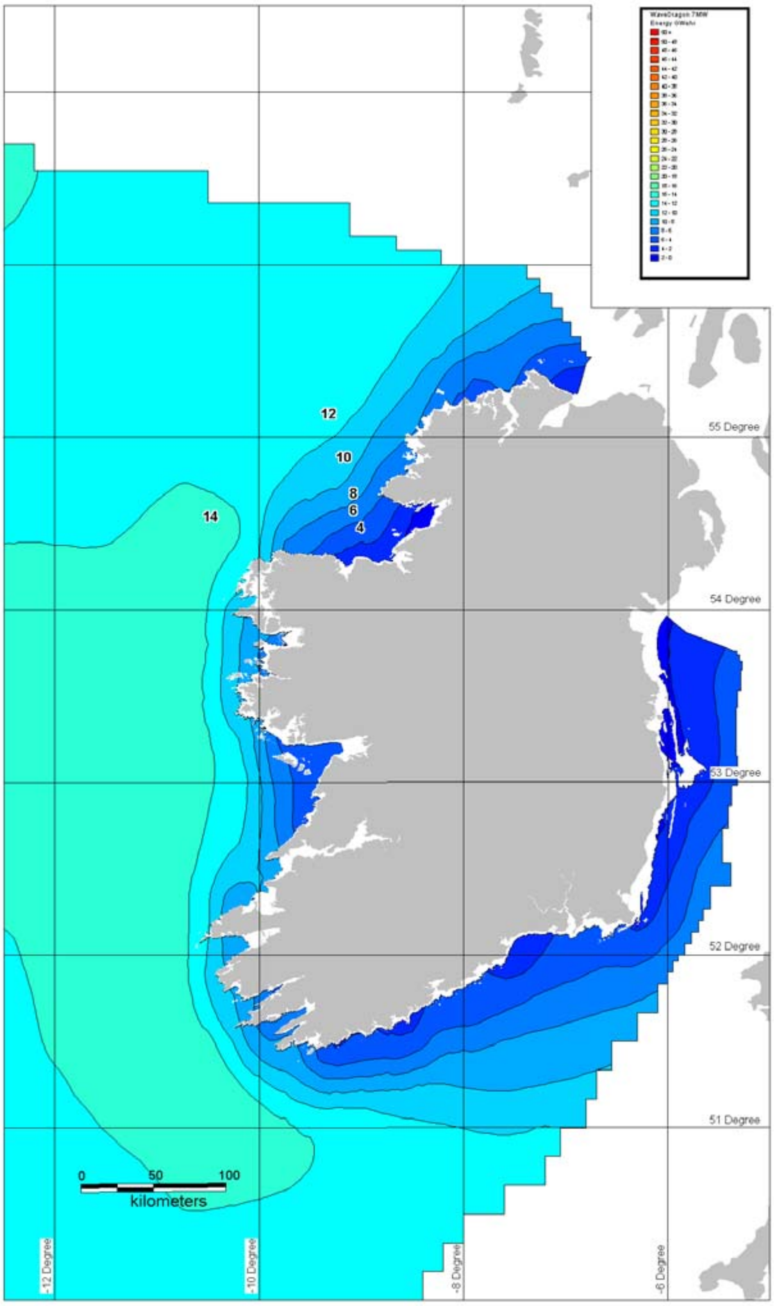


Fig. A8-7 Mean Seasonal Technical Energy Resource (WaveDragon) - Autumn GWhe/km



ESB International
Environmental Services 2005

Fig. A8-8 Mean Seasonal Technical Energy Resource (WaveDragon) - Winter GWhe/km

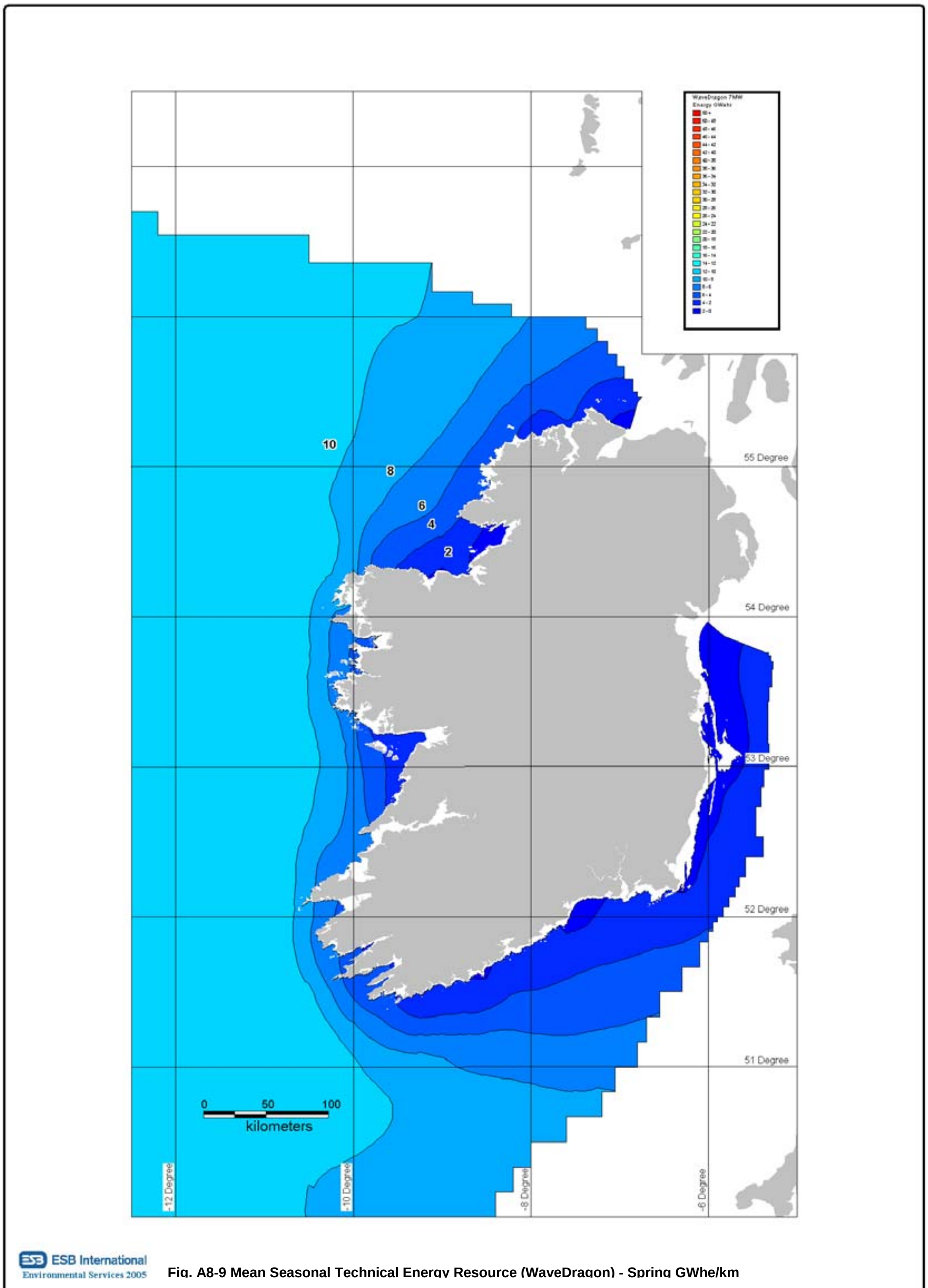
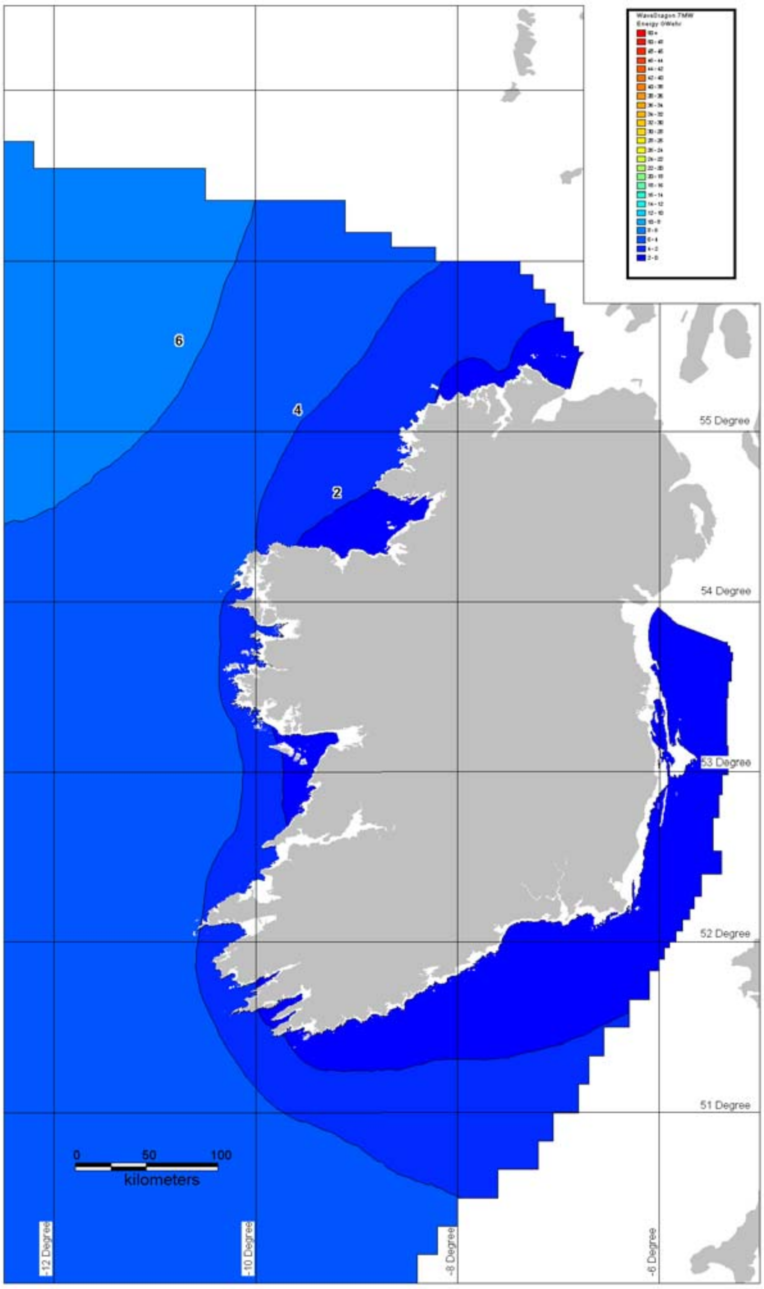
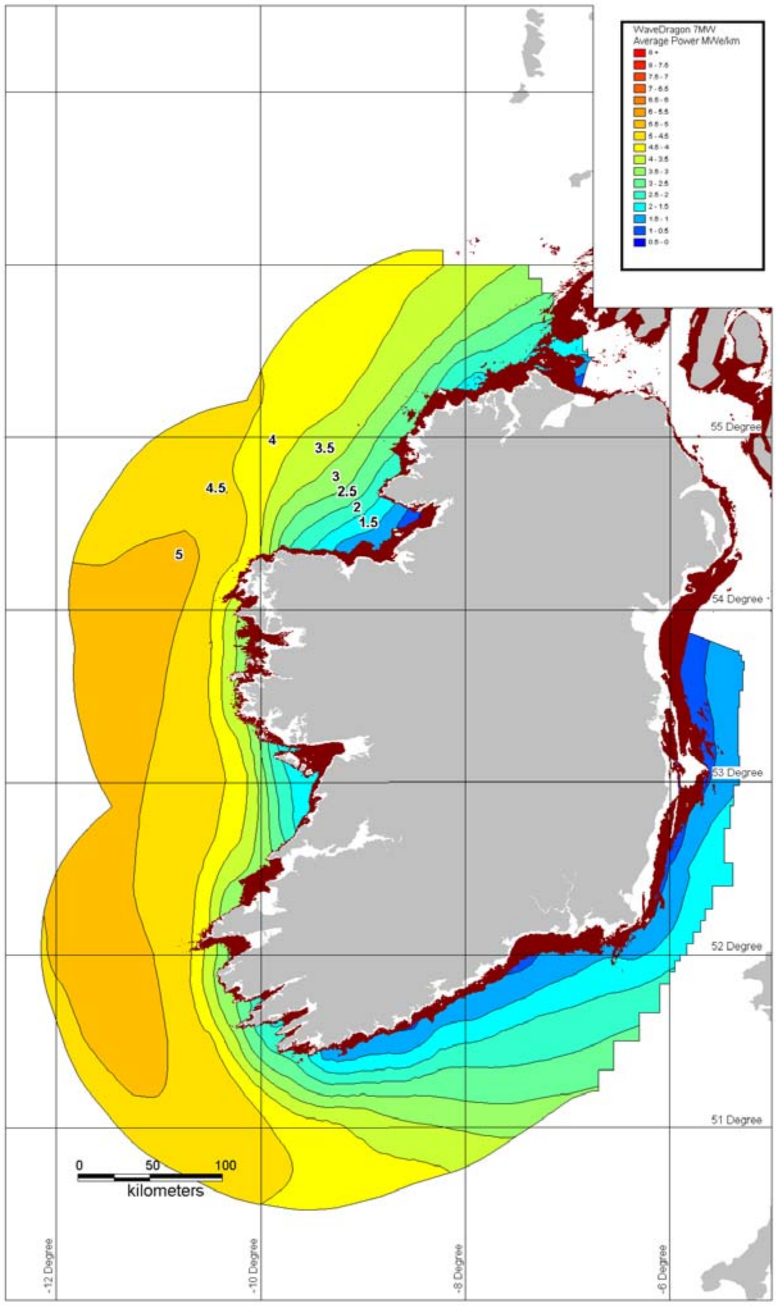


Fig. A8-9 Mean Seasonal Technical Energy Resource (WaveDragon) - Spring GWhe/km



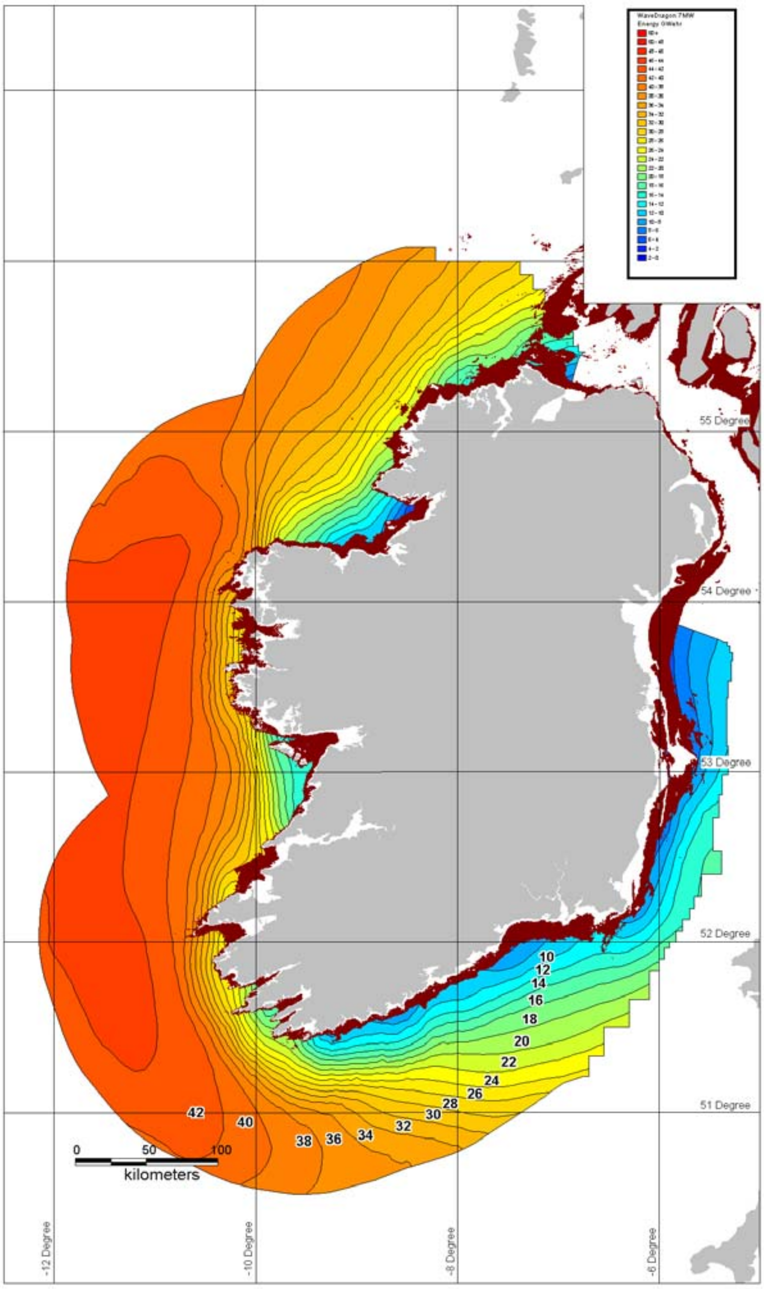
ESB International Environmental Services 2005 Fig No. 10 **Fig. A8-10 Mean Seasonal Technical Energy Resource (WaveDragon) - Summer GWhe/km**



ESB International
Environmental Services 2005

Fig N

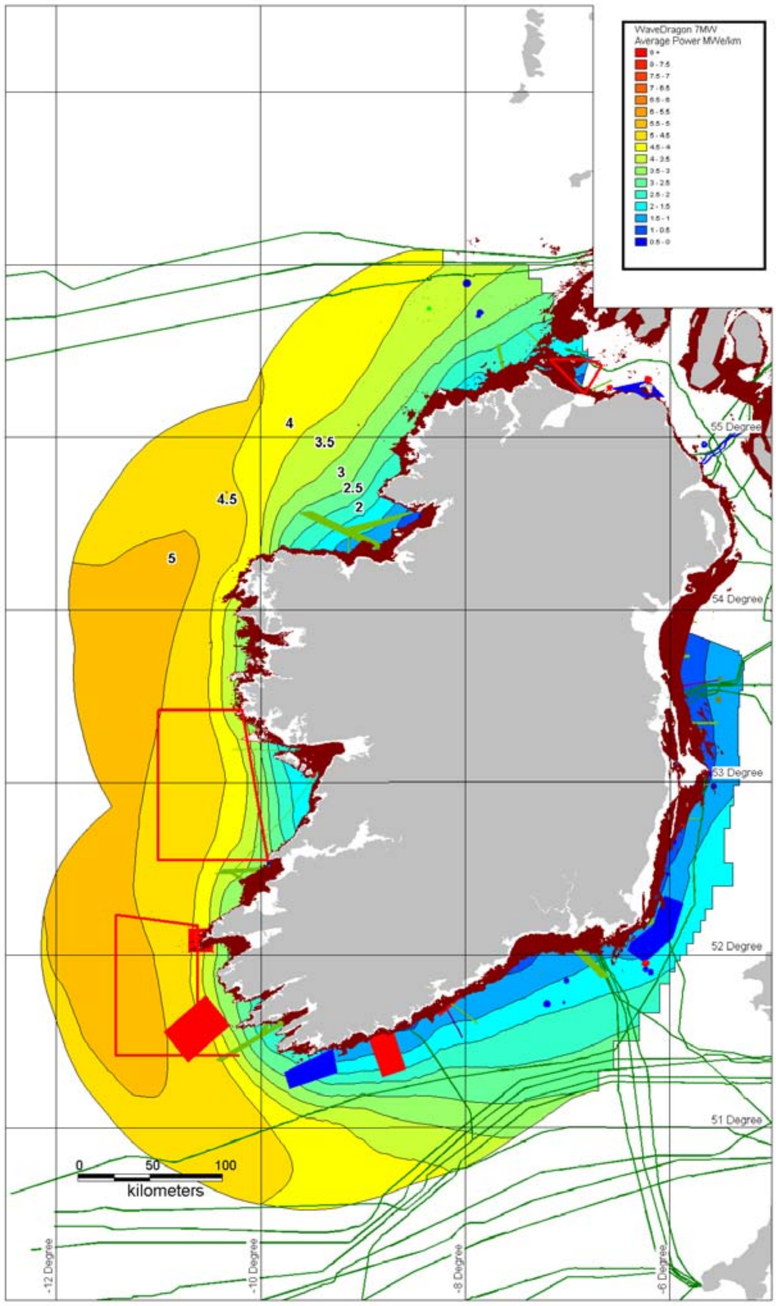
Fig. A8-11 Mean Annual Practicable Power Resource (WaveDragon) MWe/km



ESB International
Environmental Services 2005

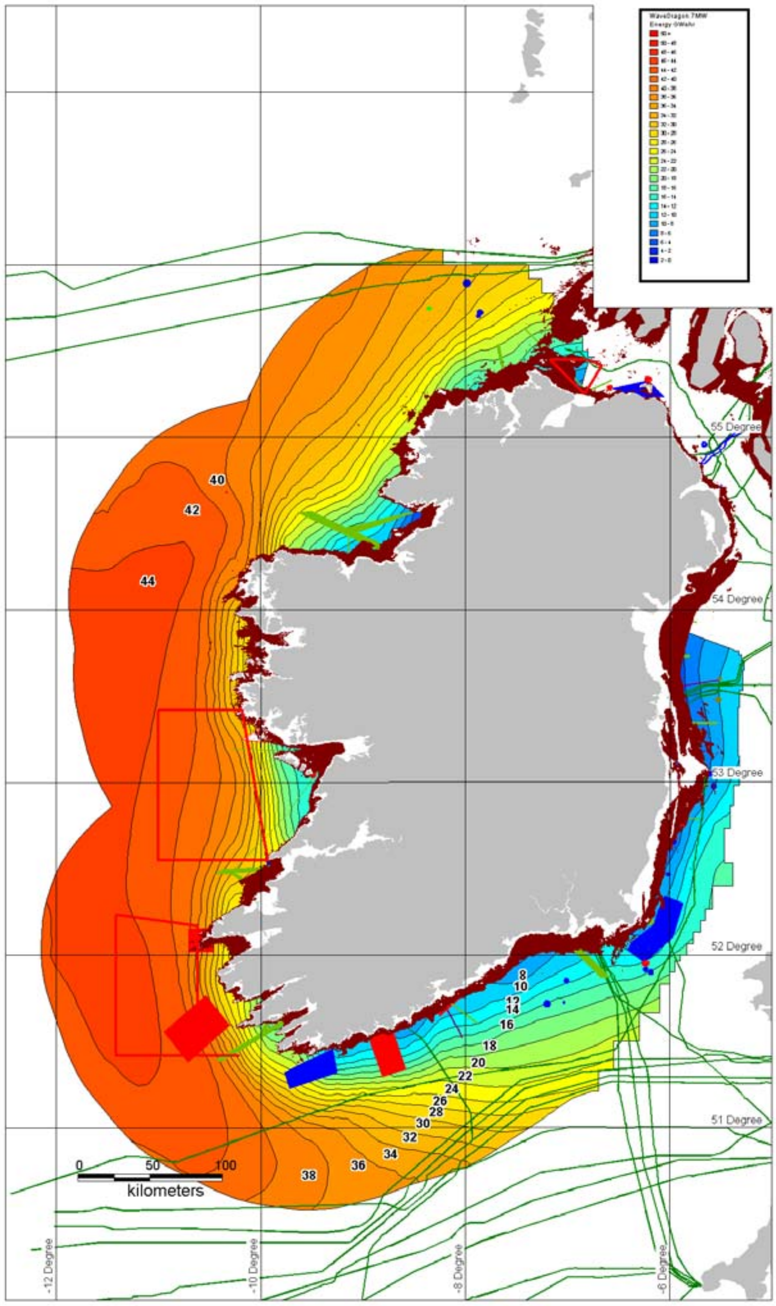
Fig No. 1:

Fig. A8-12 Mean Annual Practicable Energy Resource (WaveDragon) GWhe/km



ESB International
Environmental Services 2005

Fig No. 1 **Fig. A8-13 Mean Annual Accessible Power Resource (WaveDragon) MWe/km**

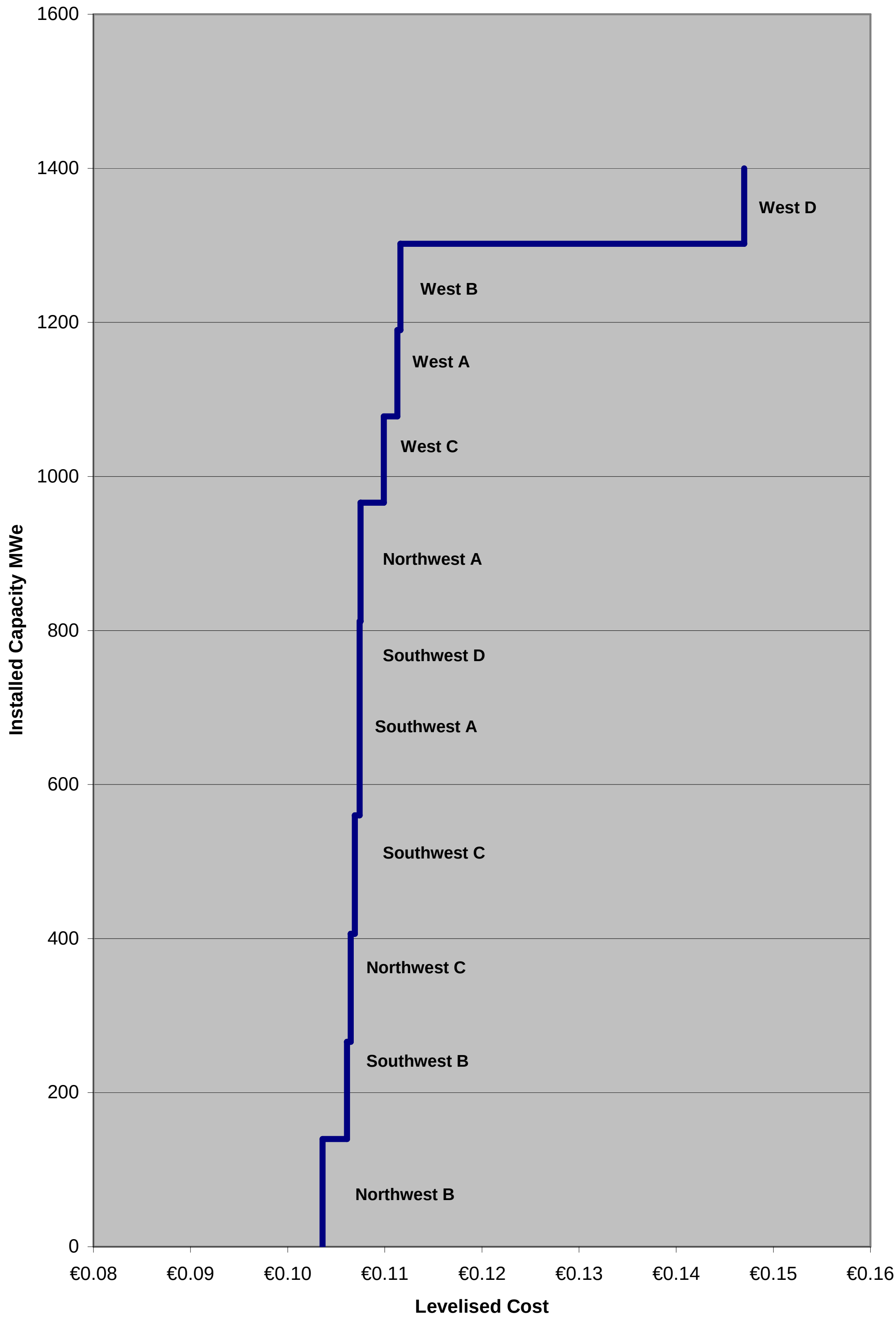


ESB International
Environmental Services 2005

Fig N Fig. A8-14 Mean Annual Accessible Energy Resource (WaveDragon) GWhe/km

Figure A8-15 –Resultant Wave Farms (1400MW) and 110kV nodes

Figure A8-16 Portfolio 6: Wave Power Resource Cost Curve



Appendix 9

Tidal Energy Resource

A9.1 Introduction

Preliminary analyses of the energy levels in tidal streams around Ireland have been made in Refs. (10, 16, 38). The sequence of identifying theoretical, technical, practicable and accessible resource has been partially employed. The analysis has been based on use of the Marine Current Turbines (MCT) technology as reference converter coupled with 2D tidal modelling using spatial grids at different levels of resolution to refine the picture at key coastal locations. The following resource levels were reported.

A9.2 Theoretical Tidal Energy Resource

The mean annual theoretical tidal resource for the whole island was estimated at 230TWh/yr. distributed between the 10m depth contour and the 12 nautical mile territorial limit. (It may be noted that the 12 mile limit is of somewhat academic significance along parts of the Northern Ireland coast that are less than 24 miles distant from the coast of Scotland). The theoretical resource is of course given in hydrodynamic rather than electrical terms.

A9.3 Technical Tidal Energy Resource

As above but confined to areas having peak current velocities exceeding 1.75m/sec. between 10.0m depth and 12 mile limit, utilising a conversion efficiency of 39%. The average resource amounts to 10.457TWhe/yr.

A9.4 Practicable Tidal Energy Resource

Following the convention now established this should be the above Technical Resource but limited to depths between 20m and 40m within which the chosen converter can operate. The cantilevered converter currently available is considered to have an installation depth limit of 40m. At greater depths tethered submersible second generation converters (e.g. similar to the tidEl machine) that are as yet unproven in full scale are considered to be applicable.

Based on an examination of eleven sites the Practicable mean annual resource was estimated at 2.633TWhe/yr. However in producing this figure Ref. (16) took account of deletions in area appropriate to shipping lanes, restricted areas, pipeline and cable wayleaves and buffer zones. These are legal entities that would more appropriately be factored in when reducing the Pacticable resource to the Accessible resource level. However at the end of the day what is important that they should be factored in at some point.

A9.5 Accessible Tidal Energy Resource

Ignoring some minor narrows on the west coast (Bulls Mouth, Dursey, Gascanane, Foyle) which contribute less than 1.5% of the total, the Accessible mean annual tidal energy resource is estimated at 914GWhe/y comprised as per Table A9.1.

Table A9.1

Key Tidal Resource Areas

Location	Energy Resource GWhe/y	
Shannon Estuary 1, 2, 3 Wexford 1 & 2 Wicklow 1, 2, 3 Inishtrahull	111 177 70 15	
RoI Subtotal		373
Strangford 1, 2 3 Copeland 4, 5 NE Coast 7, 8, 9	130 138 273	
NI Subtotal		541
All Island Total		914

Although the term ‘viable resource’ is used in Ref. 16, this is a function of the market at any given time and is probably best left unstated at this stage, as it refers to that fraction (if any) of the tidal resource that can be delivered at a price/kWhe below that of the best new entrant to the market place. It should also be noted that within the 12 mile limit but at depths exceeding 40m there is a considerable additional resource (circa 3.123 TWhe/yr) that could conceptually be delivered by as yet unproven ‘second generation’ converters.

Within the areas tabulated above the projected cost of energy delivered varies depending on the

- Depth of water
- Size of turbine
- No. of turbines per group
- Distance to network connection point
- Capacity and voltage of local network

Preliminary estimates of cost/kWhe delivered had been made in the referenced reports for NI and RoI and these figures have been updated to 2006 as hereunder. (Table A9.2). These permit a preliminary relative ranking of the accessible sites to be made (Fig. A9-1) to show the difference in the nature of the resource in the Republic and Northern Ireland. Final levelised cost calculations have been made using updated costs provided by Marine Current Turbines. (Table A9.3)

Table A9-2

Whole Island Tidal Energy Resource – Ranked on Projected Levelised Cost (2006)

Rank	Location *	Capacity MWe	Energy GWhe/yr	Levelised Cost €c/kWhe	First Generation
1	Shannon 3.1	8.24	31.99	11.18	(Republic of Ireland)
2	" 3.2	5.46	18.53	12.04	
3	" 3.3	5.46	18.53	12.12	
4	Wexford 1	26.9	97.31	12.44	
5	Wexford 2	22.18	80.14	12.52	(Mean Annual Energy
6	Shannon 1.2	3.1	10.19	14.15	Output/MWe
7	Shannon 1.1	3.7	11.64	14.52	Installed =
8	Shannon 2.1	4.26	13.25	15.07	3.31GWhe/MW eyr
9	Shannon 1.3	2.3	6.88	17.15	
10	Wicklow 3	14.07	41.08	17.51	
11	Inistrahull	6.67	15.06	21.29	
12	Wicklow 2	4.7	13.36	21.54	
13	Wicklow 1	5.9	15.86	21.79	
	Sub-Total	**112.94**	**373.82**		
1	Strangford 2B**	10.1	45.47	4.86	First Generation
2	Strangford 1**	9.5	41.85	5.13	(Northern Ireland)
3	NE Coast 7A**	27.14	124.5	5.36	
4	NE Coast 7B**	18.6	87.67	5.55	
5	Strangford 3	10.3	49.83	5.76	
6	NE Coast 9	11.8	51.0	7.0	(Mean Annual
7	Copeland 4B	15.0	61.13	7.45	Energy Output/

** Selected for Portfolios 1 to 4, giving 63.5MW

Rank	Location *	Capacity MWe	Energy GWhe/yr	Levelised Cost €c/kWhe	First Generation
8	NE Coast 8	10	40.4	7.55	MWe installed =
9	Copeland 4A	12	45.27	8.33	4.06 GWhe/MWeyr
10	Strangford 2A	1.6	6.87	8.6	
11	Copeland 5	18.4	32.02	10.26	
	Sub-Total	**144.44**	**586.01**		

					Second
1	NE Coast Z2	39[***]	184.88	5.47	Generation
2	“ X2	39	184.88	5.47	(Northern Ireland)
3	“ Y2	156	739.52	5.47	
4	“ Z3	65	323.29	5.47	(Mean Annual
5	“ X1	65	323.29	6.1	Energy Output/
6	“ Y1	260	1293.16	6.1	MWe installed =
7	“ Z1	16	73.95	6.39	4.88GWhe/MWeyr
	Sub total	**640**	**3122.97**		

* See Reference 10 for site locations

This shows that the Northern Ireland sites appear to be significantly more attractive than those in the Republic. Using first generation converters the scale of the installations makes them equivalent to small/medium sized wind farms, facing high installation and probably high operating costs.

A9.6 Second Generation Tidal Converters

These are anchored submerged converters that can be placed in greater depths and stronger currents than the fixed bed mounted type. Examples include the TidEl system. These are presently at the modelling or prefield trial stages and realistic costs have yet to be established.

The case for these systems is that they should reduce capital costs and installation time while being able to tap into higher energy tidal streams than the first generation machines. Potential for economy of scale and streamlined offsite production should be therefore enhanced. The corollary is that unit cost of

[***] Selected sites for Portfolios 5, 6 giving an additional 143MWe to total 208MWe

electricity supplied should be at least equal to or better than that provided by the bed mounted type. The extent of the resource is indicated on Table A9.3, without specific costs at this stage.

A9.7 Timing

The present position is that a demonstration MCT bed mounted converter is scheduled for installation in 2007 at Strangford location 2A with a particular focus on proving the technical and environmental compatibility of the technology at an important location where this can be closely monitored. The project had been scheduled to operate for a five year period but installation has been delayed.

Although the converter components have been fabricated and await delivery to site it is difficult to foresee production systems becoming available prior to completion and evaluation of the results of such a full-scale demonstration system. Thus 2010 would appear (at this point) to be the earliest date at which these installations could take place even if the costs proved favourable. Unfortunately, unless fully proven elsewhere, the hurdle of the relatively small higher cost projects will have to be negotiated so that operating and financing experience can be built up before the larger more attractive projects can be developed. (MCT is understood to be considering the development of a 10MW tide farm at a favourable location near Anglesea as a pilot development. This may accelerate the overall development process). There is also some prospect that second generation converters may ‘leap frog’ the first generation technology before it has exploited the sites identified above. On balance the installation of perhaps 20MW by 2015 and 65MW by 2020 is considered feasible at this stage.

Table A9.3

Tidal Sites Ranked to meet Portfolio Requirements

Portfolio	Site	Capacity (MWe)	110kV	Balance (MWe)	Levelised Cost €	Generation
1 – 4 (70MWe Req.)	2B 1 7A 7B	10.1 9.5 27.14 18.6 (65.34)	Ballynahinch Ballynahinch Loguestown Loguestown	Shortfall 4.7	0.216 0.215 0.236 0.248	1st
5 - 6 (200MWe Req.)	Z2 X2 Y2	39 39 65 (143)	Larne Loguestown Larne	Surplus 8.34	0.102 0.099 0.097	2nd
		(208.34)				

A9.8Conclusions

(1) Evaluation of the tidal stream resource, within the 12NM limit, round the island of Ireland has been based on the referenced reports and contact with converter developers, both of first (20m < depth < 40m) and second generation (depths > 40m) systems.

(2) The **theoretical** tidal stream resource is estimated at 230TWh/yr in hydrodynamic terms.

(3) Utilising first generation bed mounted converters of the MCT type at locations with peak current velocities exceeding 1.75m/sec. and a conversion efficiency of 39% yields a **technical** energy resource of 10.46TWhe/yr.

(4) Focussing on 11 key sites north and south the mean annual **practicable** resource falls to 2.63TWhe/yr (elec.)

(5) Elimination of legally constrained and minor areas leads to a residual **accessible** energy resource of 541GWhe/yr for Northern Ireland and 373GWhe/yr for the Republic, totalling 914GWhe/yr. (First Generation).

(6) A much larger second generation resource of 3.1TWhe/yr is estimated to be available primarily off Northern Ireland. It remains to be seen when this technology becomes commercially available and whether the implied capacity factors can be achieved or not.

(7) Capacity factors implied by the yields of Table A9-2 range between 0.19 and 0.57 and have been questioned on the basis that they may depend on particularly favourable ratios between neap and spring tide current velocity.

It has been shown that by effectively derating the electrical capacity of tidal turbines to a value below the implied mechanical capacity it is possible to increase capacity factor in the 50m diam. installation of Table A9-2 to 0.42.

However bearing in mind the relatively small scale of the projected tidal installations called for in the Portfolio this is not an unduly significant issue at this stage. Most commentators agree that the real commercial success or otherwise of tidal energy will depend on second generation machines.

(8) An initial costing of first generation technology at the respective sites allows a preliminary ranking to be made. This shows that the Northern Ireland sites are uniformly more cost effective than these in the Republic. (Fig. A9.1)

(9) Bearing in mind that this is a new technology and the competitive advantages available to other technologies it is considered that installation might credibly range between 2MWe (2010), 12MWe (2012) 20MWe (2015) and 70MWe (2020). This would lead to a shortfall of 130MWe for Portfolios 5 & 6 in 2020 although satisfying the needs of Portfolios 1 to 4.

(10) The projected levelised costs of the second generation tidal current farms bears comparison with those of the wave farms off the west coast although economy of scale favours the latter.

(11) Assuming an active programme of installation of first **and** second generation converters proves possible, the respective portfolio requirements can however be met by the sites listed in Table A9.3.

Fig. A9-1 - Projected Resource Cost Curves for installed capacity utilising first and second generation tidal conversion technology at ranked sites (Table A9-2)

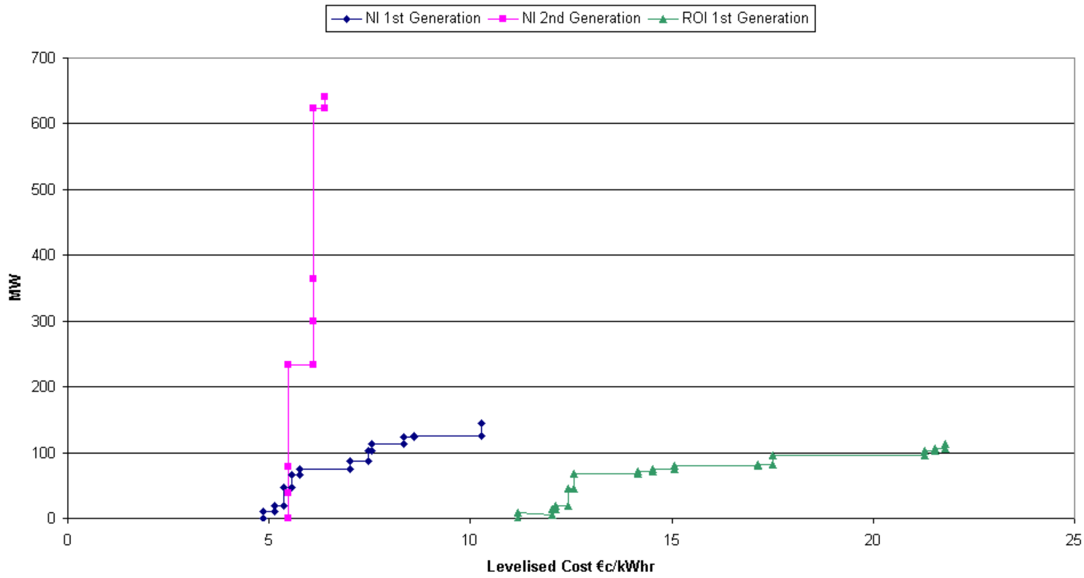


Figure A9.2 – Peak Spring Tidal Speeds North & North East coasts

(Based on Ref. 10)

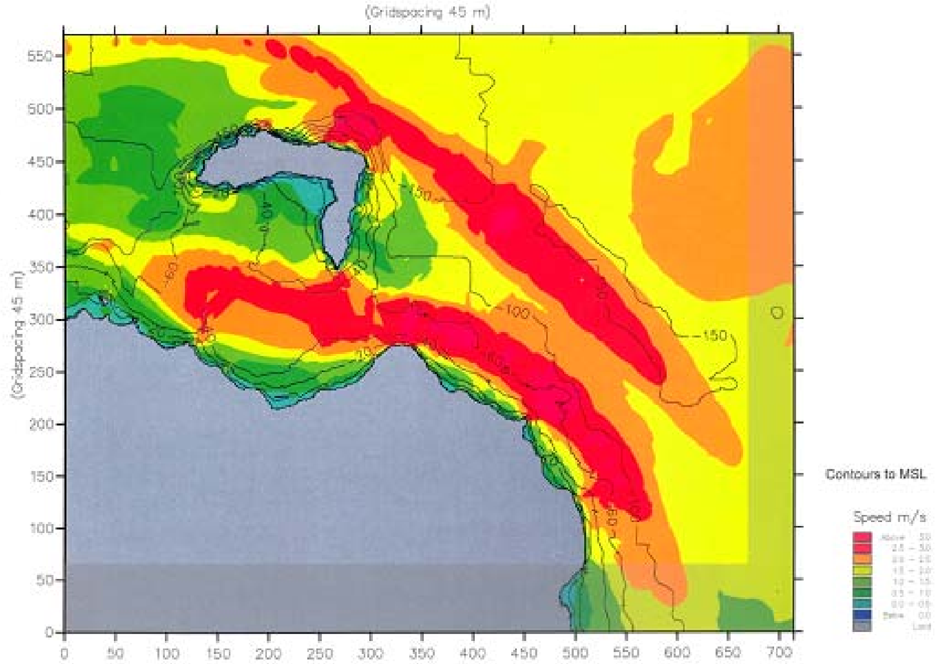


Figure A9.3 – Spatial Distribution of Tidal Stream Plant for Portfolios 1 to 4

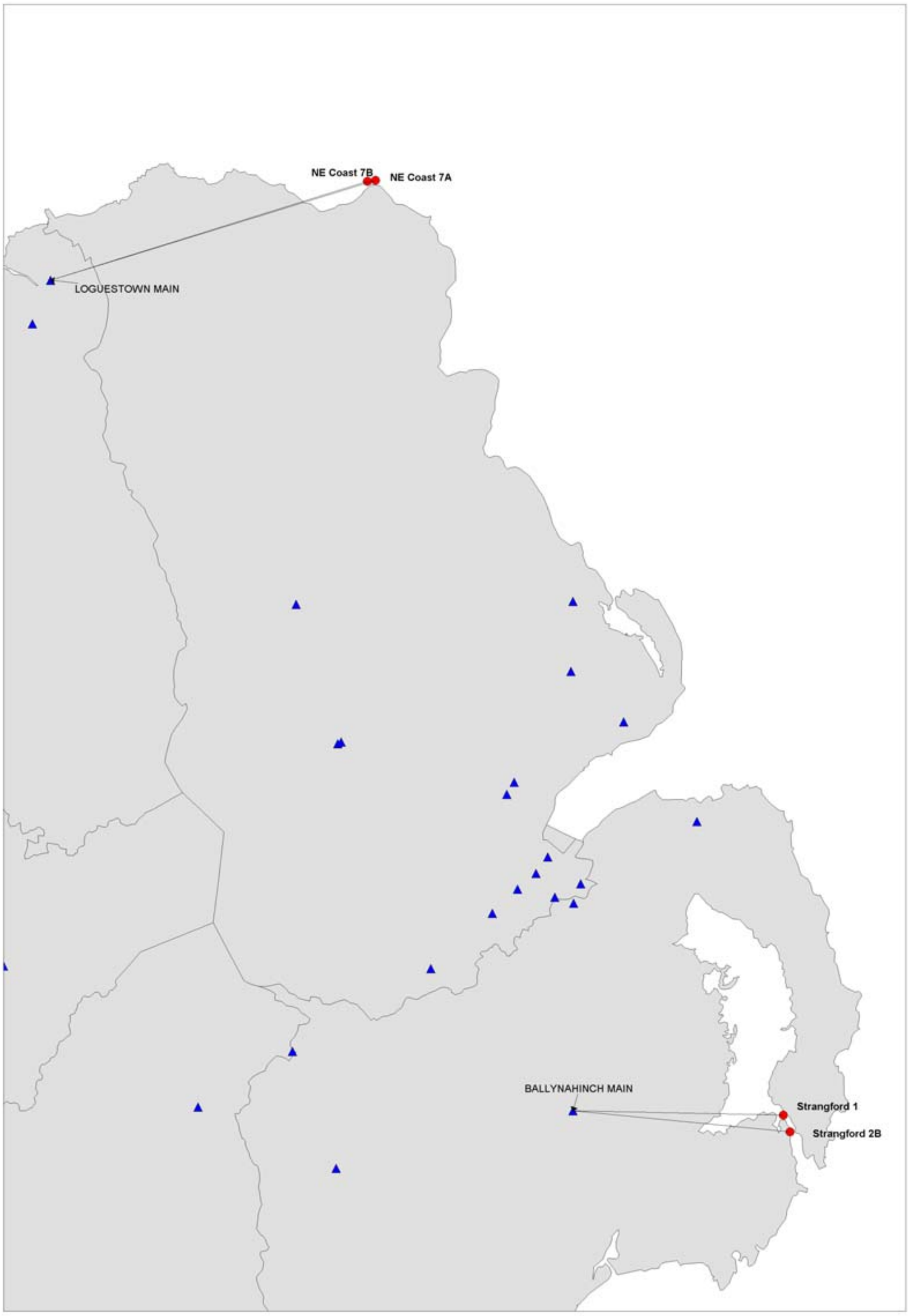


Figure A9.4 - Spatial Distribution of Tidal Stream Plant for Portfolios 5 & 6

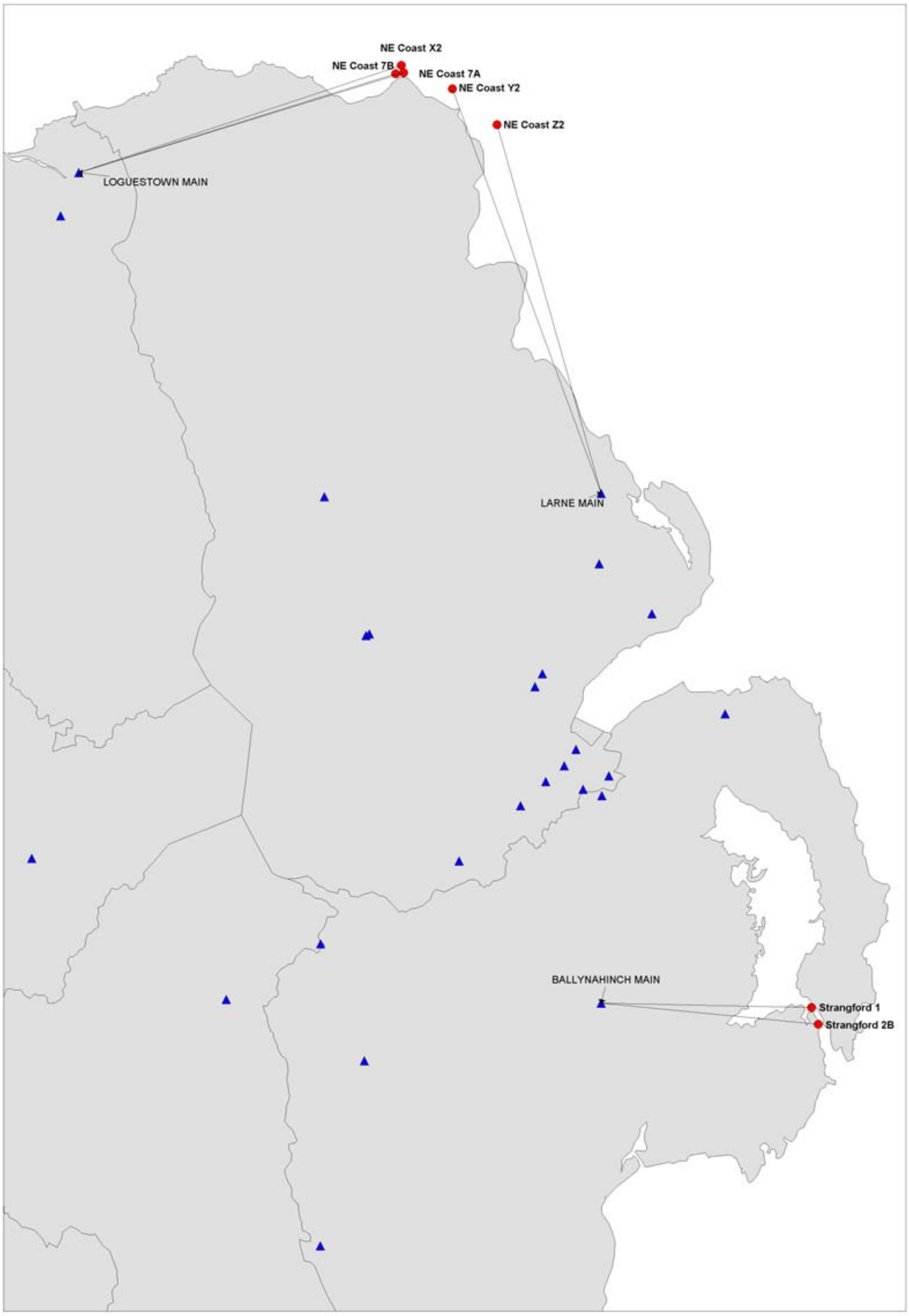
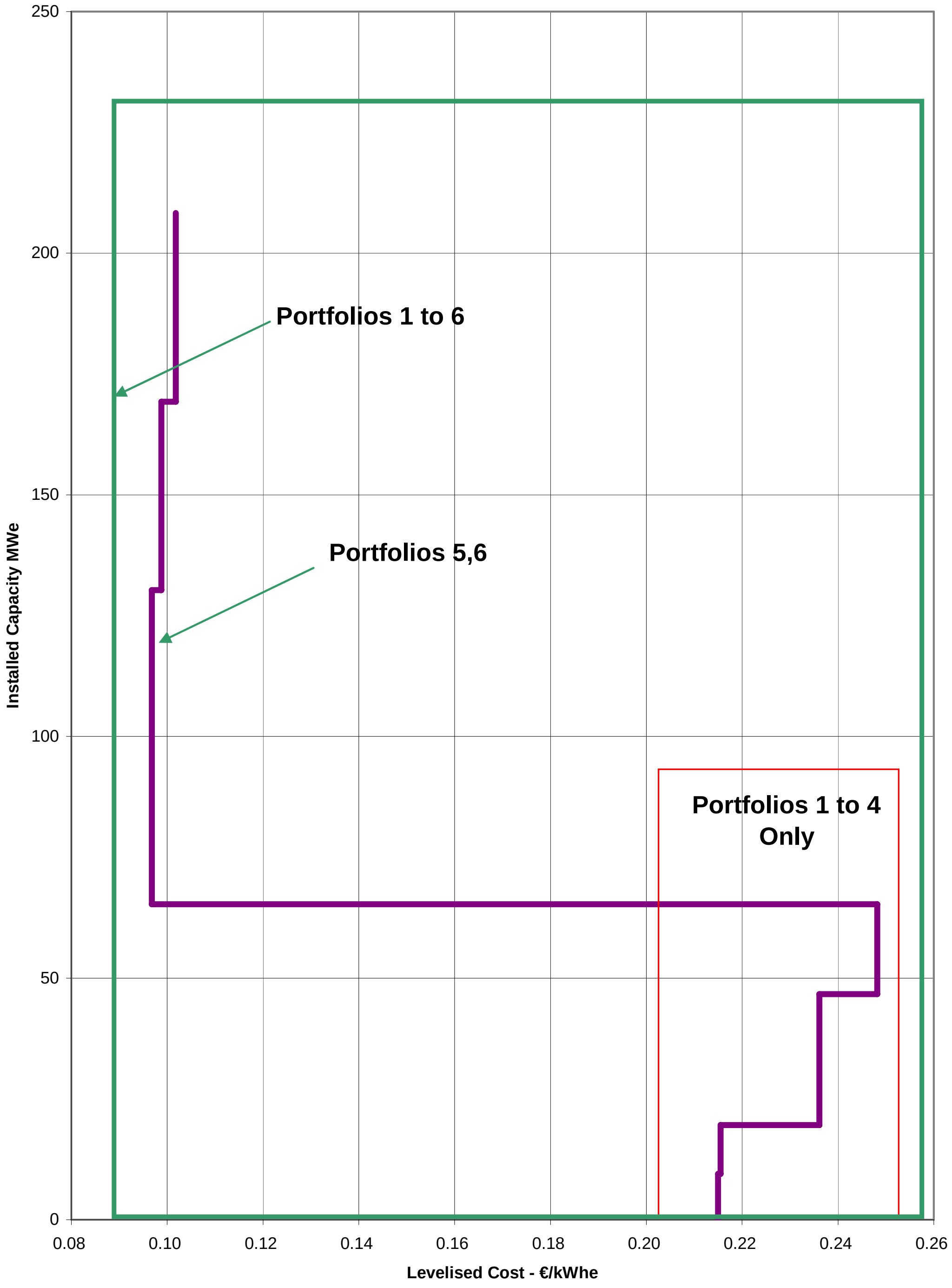


Figure A9.5 - Portfolios 1 - 6: Tidal Power Resource Cost Curve



Appendix 10
Conversions, Factors and Equations for
Estimation of Levelised Cost Inputs : Biomass

A10.1 Introduction

The equations are derived variously from known plant costs, suppliers quotations or other referenced studies and include indexation for inflation. However some variation may occur where intercurrency exchange rates are involved. In the case of MBT and energy from waste projects the costs reflect the necessary waste separation and recovery facilities that are a prerequisite with such projects.

In use the appropriate equation is solved using the given plant capacity (MWe or t/yr) to obtain Capital and O&M Cost. Knowing the site location and nearest 110kV mode the indicative transmission cost is estimated and added to the capital cost for estimation of levelised cost. These costs are exclusive of gate fees, grants, carbon allowances, ROCs or other sources of benefit that may arise in a particular case.

A10.2 Equations

Abbreviations used are:

Electrical Plant Capacity: MWe

Waste Throughput Capacity : t (tonnes/yr)

Transmission Network Connection Capital Cost : T

Equation No. & Type

1. Energy from Waste : Landfill Gas : Fig. A10.1

1.1 Capital Cost : €M = -0.0155(MWe)^2 + 0.8592(MWe) + 0.7286

1.2 O&M Cost : €M/yr = -0.0023(MWe)^2 + 0.127(MWe) + 0.108

For use in conjunction with Table A5.3.1 (cost of pipework excluded as it is necessary for obligatory flaring in any event).

2. Energy from Waste : MSW Incineration : Fig. A10.2

2.1 Capital Cost : €M = (0.0393)(MWe)^2 + 0.6924(MWe) + 60.349) +T

2.2 O&M Cost : €M/yr = (0.0993(MWe) + 2.2277)

3. Energy from Waste:BMW–MBT + Advanced Technology (MWe): Fig. A10.3

3.1 Capital Cost : €M = (7.0848)(MWe) + 20.598) +T (incl. presorting)

3.2 Capital Cost : €M = (4.1257)(MWe) + (7.88) + T (efw without presorting)

3.3 O&M Cost : €M/yr = (0.473(MWe) + 7.88)

4. Energy from Waste : BMW–MBT + Advanced Technology (kt/yr) : Fig. A10.4

4.1 Capital Cost : €M = (0.3876)(kt) + 20.4) +T (incl. presorting)

4.2 Capital Cost : €M = (0.2257)(kt) + (7.7678) + T (efw without presorting)

4.3 O&M Cost : €M/yr = (0.0259(kt) + 2.7478)

5. Energy from Waste : Poultry Litter – Incineration (MWe) : Fig. A10.5

5.1 Capital Cost : €M = (3.5072)(MWe) – 2.3754) +T

5.2 O&M Cost : €M/yr = (0.1789(MWe) – 0.3211)

6.Energy from Waste : Poultry Litter - Incineration (kt/yr) : Fig. A10.6

6.1 Capital Cost : €M = (0.3012) (kt/yr) – 8.0907) +T

6.2 O&M Cost : €M/yr = (0.0152 (kt/yr) – 0.595

7.Energy from Waste : Wet Agri Slurry – AD (MWe) : Fig. A10.7

7.1 Capital Cost : €M = (0.1448)$(MWe)^2$ + (4.0128)(MWe) + 2.541 + T

7.2 O&M Cost : €M/yr = (-0.0271 $(MWe)^2$ + 0.7079(MWe) -0.0136

8.Energy from Waste : Wet Agri. Slurry – AD (t/yr) : Fig. A10.8

8.1 Capital Cost : €M = (5 x $10^{-6}(kt/yr)^2$ + 0.0241 (kt/yr) + 2.541) + T

8.2 O&M Cost : €M/yr = ($-10^{-6}(kt/yr)^2$ + 0.0042 (kt/yr) – 0.0136) = -10^{-6} $(kt/yr)^2$ + 0.00 42(kt/yr) – 0.0136)

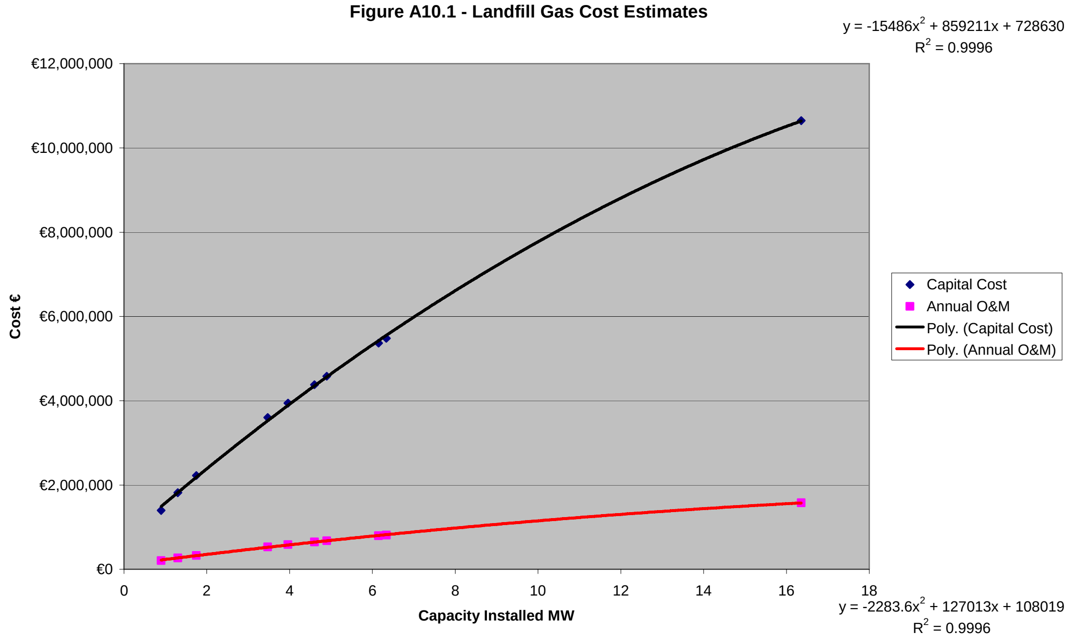
9.Energy from Waste : Wood Fuelled Sawmill type CHP (MWe) : Fig. A10.9

9.1 Capital Cost : €M = (0.2429 $(MWe)^2$ – 0.5306 (MWe) + 6.4299) + T

9.2 O&M Cost : €M/yr = (0.0136 $(MWe)^2$ – 0.0242 (MWe) + 0.3504)

9.3 Fuel Cost : €M/yr = (0.1114 (MWe) + 0.671)

Figure A10.1 - Landfill Gas Cost Estimates



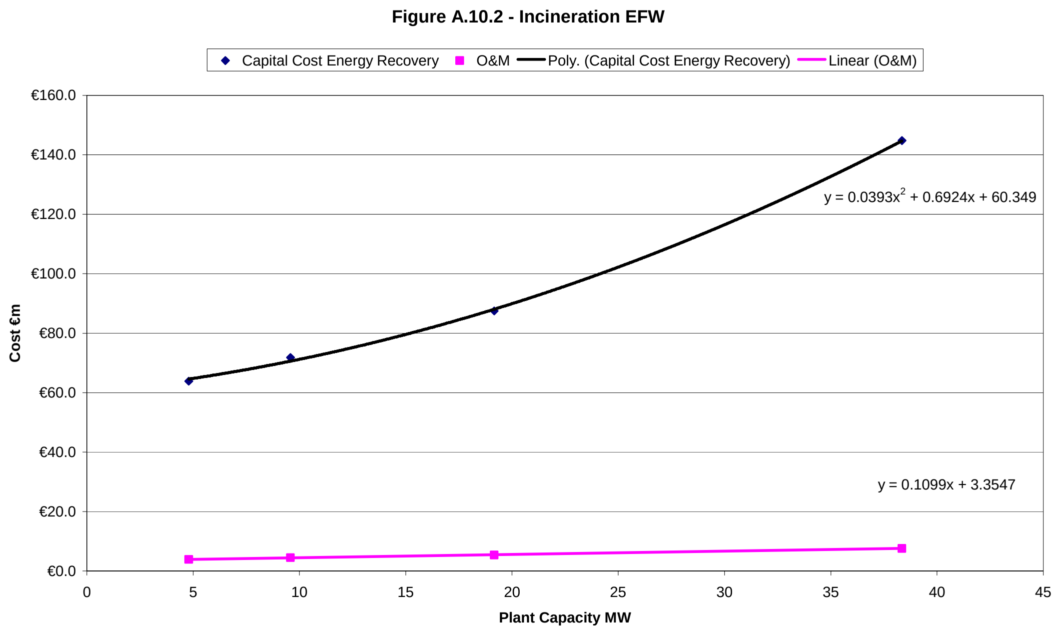


Figure A.10.2 - Incineration EFW
Capital Cost Energy Recovery
O&M
Poly. (Capital Cost Energy Recovery)
Linear (O&M)
y = 0.0393x2 + 0.6924x + 60.349
y = 0.1099x + 3.3547
Cost €m
Plant Capacity MW
€160.0
€140.0
€120.0
€100.0
€80.0
€60.0
€40.0
€20.0
€0.0
0
5
10
15
20
25
30
35
40
45

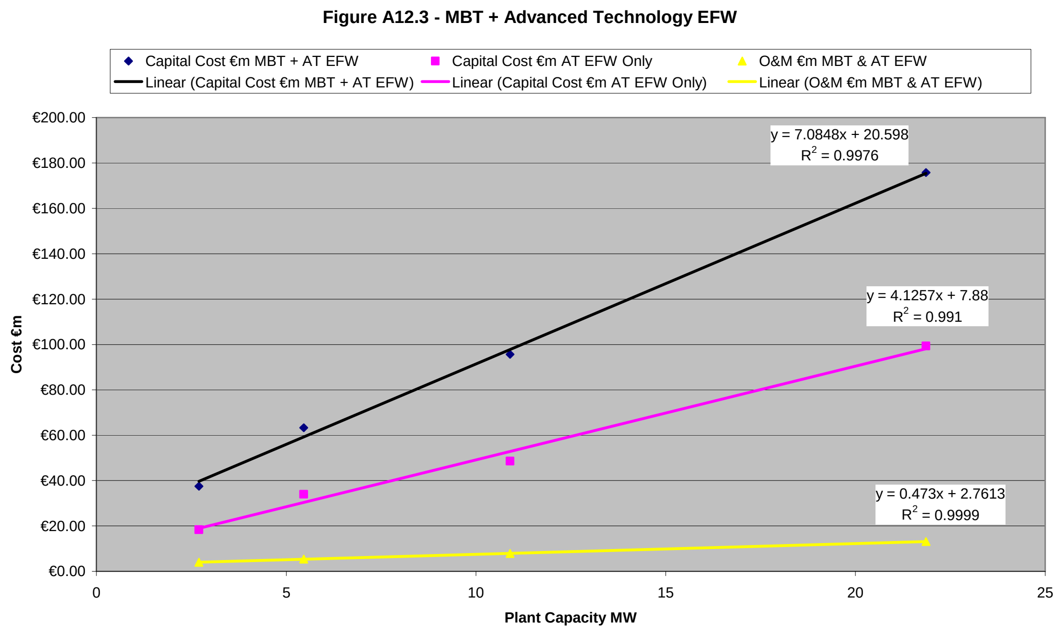


Figure A12.3 - MBT + Advanced Technology EFW
Capital Cost €m MBT + AT EFW
Capital Cost €m AT EFW Only
O&M €m MBT & AT EFW
Linear (Capital Cost €m MBT + AT EFW)
Linear (Capital Cost €m AT EFW Only)
Linear (O&M €m MBT & AT EFW)
y = 7.0848x + 20.598
R2 = 0.9976
y = 4.1257x + 7.88
R2 = 0.991
y = 0.473x + 2.7613
R2 = 0.9999
Cost €m
Plant Capacity MW
€200.00
€180.00
€160.00
€140.00
€120.00
€100.00
€80.00
€60.00
€40.00
€20.00
€0.00
0
5
10
15
20
25

Figure A12.4 - MBT + Advanced Technology EFW

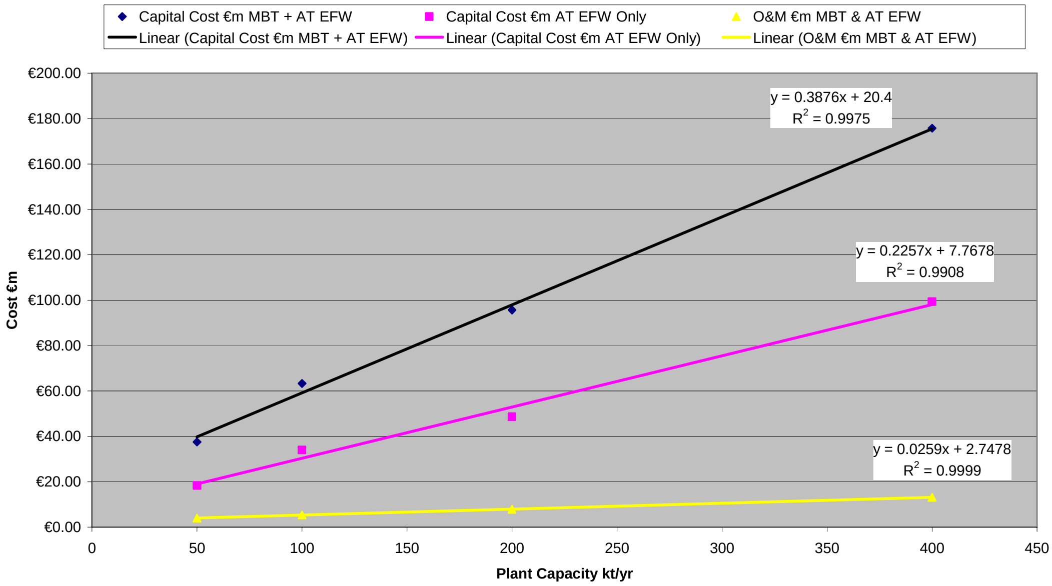
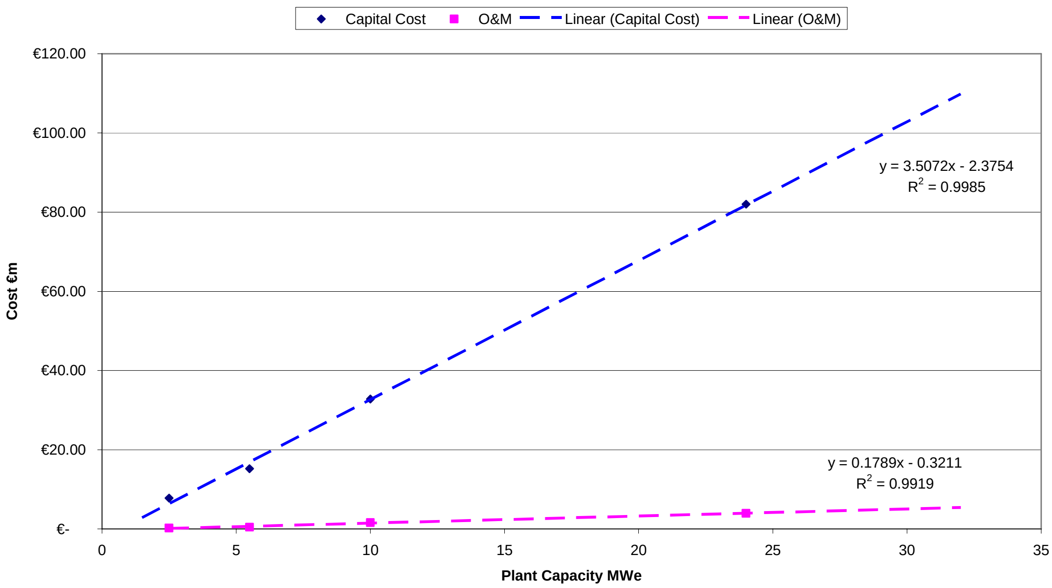


Figure A10.5 - Chicken Litter Plant Cost Estimates



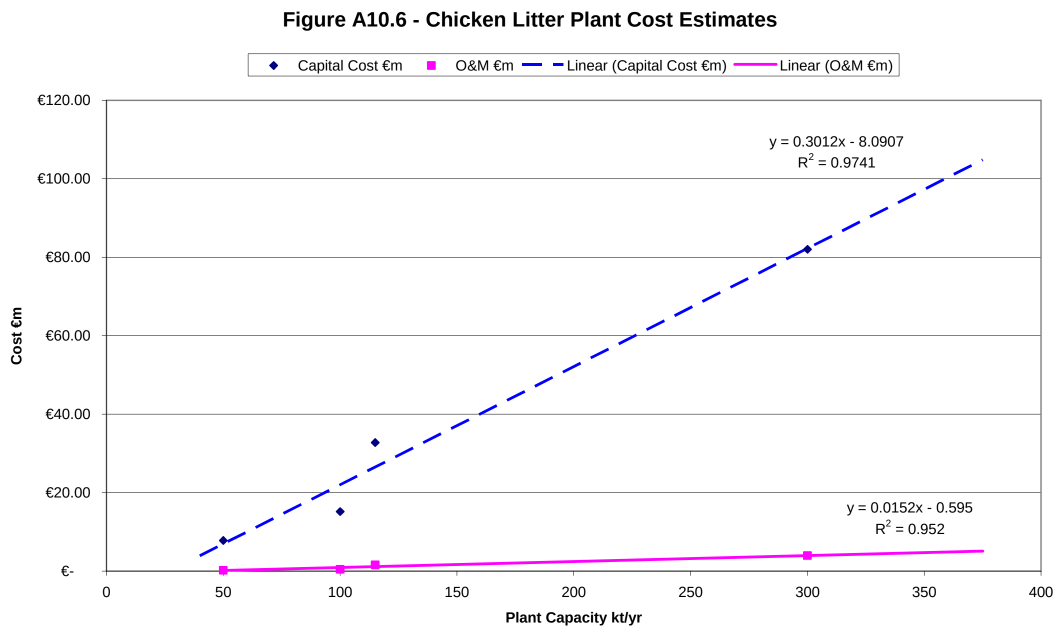


Figure A10.6 - Chicken Litter Plant Cost Estimates
Capital Cost €m
O&M €m
Linear (Capital Cost €m)
Linear (O&M €m)
€120.00
€100.00
€80.00
€60.00
€40.00
€20.00
€-
Cost €m
y = 0.3012x - 8.0907
R2 = 0.9741
y = 0.0152x - 0.595
R2 = 0.952
0
50
100
150
200
250
300
350
400
Plant Capacity kt/yr

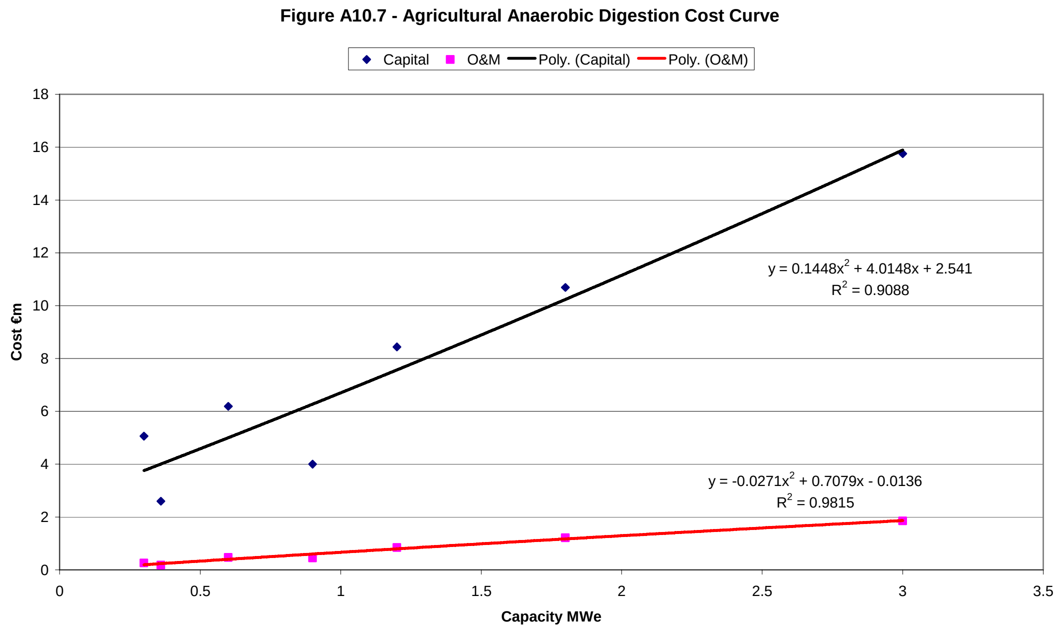
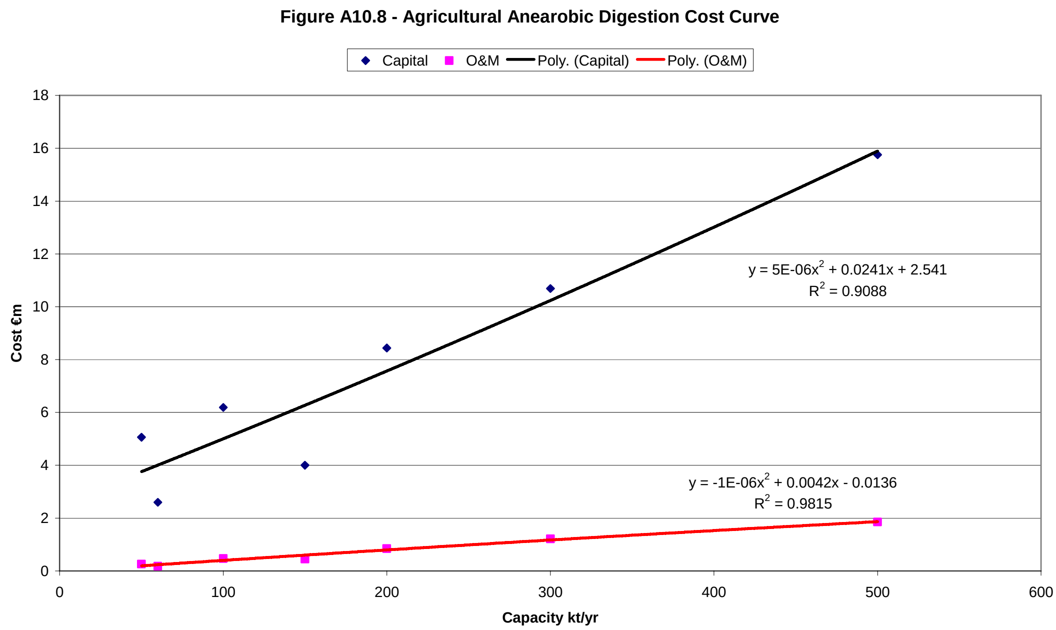
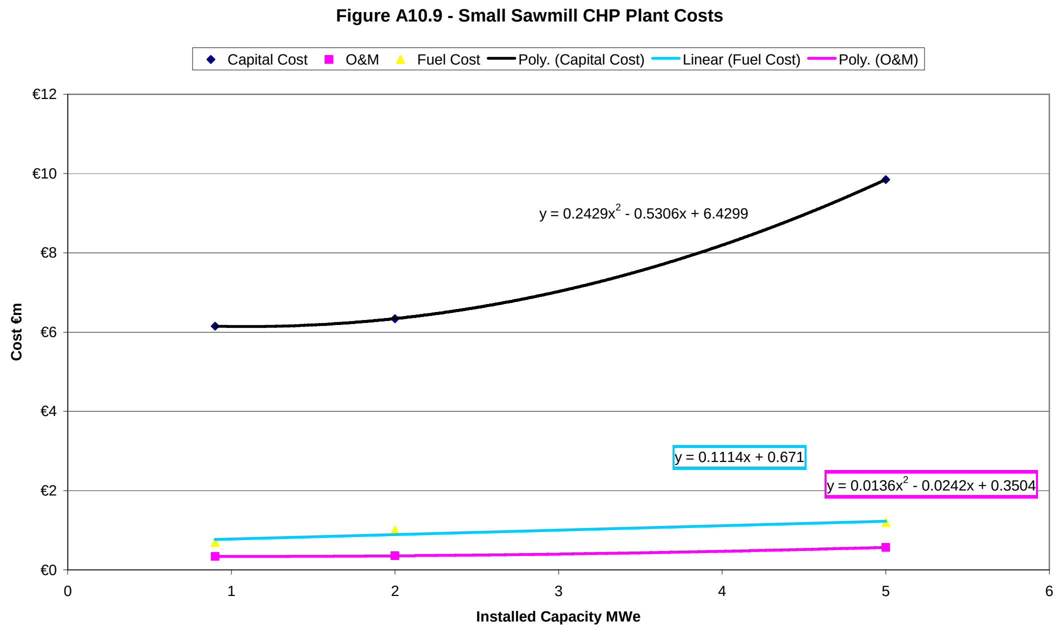


Figure A10.7 - Agricultural Anaerobic Digestion Cost Curve
Capital
O&M
Poly. (Capital)
Poly. (O&M)
18
16
14
12
10
8
6
4
2
0
Cost €m
y = 0.1448x2 + 4.0148x + 2.541
R2 = 0.9088
y = -0.0271x2 + 0.7079x - 0.0136
R2 = 0.9815
0
0.5
1
1.5
2
2.5
3
3.5
Capacity MWe





10.3 Factors & Conversions Used

1. Municipal Waste

Elec. Equivalent/t of BMW (via AD)	407kWhe
Elec. Equivalent/t of BMW (via MBT + SRF)	928kWhe
Elec. Equivalent of BMW (via Pyrolysis/Gasification)	789kWhe
Elec. Equivalent/t of Residues (via Incineration)	714kWhe

2. Agri Wastes

Cattle Slurry	167kWht/t – 50.1kWhe/t (η = 0.3)
Pig Slurry	166kWht/t – 49.8kWhe/t (η = 0.3)
Poultry Slurry	518kWht/t – 155.4kWhe/t (η = 0.3)
Food Process	294kWht/t – 88.2kWhe/t (η = 0.3)

3. Wood Biomass

SRC Moisture Content	55-60%
SRC Calorific Value	1.73MWht/t
Av. SRC Yield	22t/Ha/Yr
SRC Energy Yield	38.06MWht/Ha
SRC Area Reqd. to fuel NMWe/yr	(N x 8760 x CF ÷ η x 1.73 x 22) (η varies 0.2 – 0.4 depending on plant)
Forest Timber	1.1 solid M^3 = 1 tonne (60-65% M.C.)

4. Fuels

1 toe	:	5.45t sawn residue
1 toe	:	7.378t pulpwood
1 toe	:	41.87GJ = 11.63MWht
1t steam coal	:	25GJ (= 4.386t pulpwood)

Energy/Power

1GWhe x 0.1343	:	MWe Rating @ CF = 0.85
1MJ/t x 0.2778	:	kWht/t

5. Currency

£0.67 = €1 = $1.38

6. Levelised Costs Basis

Discount Rate: 8%

Project Duration: 20 years.

Appendix 11

Network Connection Costs

A11.1 Introduction

Network connection costs are a function of numerous variables including:

- The capacity of the existing (or planned) network in the vicinity of the point of connection (including switching station/transformer capacity)
- The voltage and current carrying capacity of the connecting line (or cable)
- Connecting line (or cable) length
- Type of terrain through which connecting line (or cable) passes
- Required commissioning date
- Potential for sharing costs with other developers
- Wayleave issues

In normal utility practice new works arise from a programme that may have a planning horizon set several years ahead of actual construction date. This allows time for the increasingly complex requirements of electrical engineerings studies, route selection environmental impact studies, wayleave procurement and planning permission processes where required. For maximum efficiency line crew work schedules are typically programmed and budgeted at least one year in advance and short term rapid responses may mean the postponement of important new or maintenance works. Some of the challenges inherent in a build up of connection requirements for renewable energy projects, often located in relatively remote areas, are noted briefly below.

A11.2 Background

Some aspects of the network connection issues associated with renewable energy projects may require clarification. From examination of material made available during the course of this study it is evident that in the earlier days ESB quoted budget construction cost figures based on the assumption that the work would be carried out by its own staff and fitted into the normal preplanned schedule of new works and maintenance on existing lines and that wayleaves would be obtained under existing ESB powers. Assuming that the connection offer was acceptable to the developer the technical design of the connection was carried out by ESB.

As the number of committed projects rose, each with dates critical to their developers objectives, pressure increased on Networks personnel already committed to a major programme of renewal and improvement to the networks both in rural areas and expanding urban areas.

Consequently contractors were brought in to supplement the available in house capacity. This arrangement works best where the contractors have a fully pre-defined work package and can work in conditions of good weather, access and clear wayleaves. Where shortcomings occur or engineering difficulties arise e.g. poor foundation conditions such as peat, rock or water logged ground, additional costs can arise. In some cases it was evident that the final costs of work done via contractors were coming in at a higher level than the original quotations supplied to the would be developers, based on the use of ESB staff. This was particularly the case where standing time due to stress of weather, wayleave difficulties or similar problems arose. The cost of foundations or civil engineering/building work at switching stations or along the lines were also variable in an era of strong construction cost escalation in the building industry due to the sustained high level of building and construction work throughout the country.

In other cases would-be developers complained of disproportionately high connection cost quotations being received from ESB and demanded CER intervention. CER having investigated the position by considering the make up of costs quoted by ESB compared with those arising in U.K. published a set of standard costs (Ref. 32) to be used in connection cost quotations. An exception was recognised as being necessary, because of the variability of civil engineering costs in different locations, where it was stipulated that the least cost tender received from a civil contractor should be used in respect of such work.

A problem with the CER costs as published was that the range of conductor sizes specified was not as extensive as might be used in making connections to particular parts of the network, especially where it was planned to cater for a group of several projects.

Table A11.1

CER Approved Charges for Generator Connections (2005)

Item	Description	Unit	Rate (€000)
1	110kV Line (300 ACSR)	km	180
2	38kV Line (300 ACSR)	km	95
3	38kV Line (100 ACSR)	km	60
4	MV Line (92/150 ACSR)	km	45
5	Station: 38kV Cubicle	No.	135
6	Station: 38kV Bay in 110kV or 38kV Station	No.	155
7	Station: MV Cubicle in 110kV Station	No.	50
8	Station: MV Cubicle with 1/F Trafo	No.	180
9	Metering: 38kV	No.	50
10	Metering: MV	No.	25
11	Stn. Uprating: 110kV New Station	No.	2600 + civils
12	Stn. Upratng: 1 @ 31.5MVA to 2 @ 31.5MVA	No.	2276
13	Stn. Uprating: 2 @ 31.5MVA to 2 @ 63MVA	No.	2500
14	Stn. Uprating: 38kV New Station 2.5MVA	No.	1,050 + civils
15	Stn. Uprating: 38kV 2 @ 5MVA to 2 @ 10MVA	No.	1500

Table A11.1 Continued…

Item	Description	Unit	Rate (€000)
16	110kV cable (up to 1km)	km	305
17	38k cable	km	110
18	MV cable	km	50
19	End Mast 38kV	No.	40
20	End Mast 110kV	No.	140

(Civil costs or cable lengths > 1km to be via lowest prequalified tender)