The Costs and Benefits of Renewable Energy in Scotland

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Abstract

This report is concerned with the application of cost-benefit analysis to issues of renewable energy development. We focus on experience in Scotland, a country which has experienced very rapid increases in new renewables capacity in recent years, and which has set world-leading targets for renewable energy as part of climate change and economic development policies. The effects of policy instruments used to incentivise renewable energy are outlined, and information on the wider economic consequences of renewables expansion is presented. The report explains how the environmental impacts (positive and negative) of renewable energy can be included within a cost-benefit analysis, and provides examples of studies which have estimated this environmental costs and benefits in monetary terms. The final section of the report suggests some lessons which Sweden can learn from the Scottish experience.

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Sammanfattning

Denna rapport handlar om tillämpningen av en kostnads-nyttoanalys på frågeställningar kring utveckling av förnybar energi. Fokus läggs på erfarenheter från Skottland, ett land som har upplevt en väldigt snabb kapacitetsökning av förnybar energi under senare år, och som har satt upp världsledande mål för förnybar energi, vilka ingår i policys kring klimatförändringar och ekonomisk utveckling. Effekterna av de policyinstrument som används som incitament för förnybar energi beskrivs, och uppgifter presenteras kring de vidare ekonomiska konsekvenserna av utökningen av förnybara energikällor. I rapporten beskrivs hur miljöeffekterna (positiva och negativa) av förnybar energi kan innefattas i en kostnads-nyttoanalys, och det ges exempel på studier där de miljömässiga kostnaderna och vinsterna har beräknats utifrån ett kostnadsperspektiv. Det presenteras även ytterligare icke-ekonomiska uppgifter, avseende sociala och politiska kostnader och vinster, vilka har uppkommit som en följd av främjande av förnybar energi. Från denna översyn av den skotska erfarenheten kring främjande av förnybar energi och i synnerhet av vindkraftverk, kan Sverige ta till sig flera lärdomar och rekommendationer, eftersom landet bedriver liknande utvecklings-projekt kring förnybar energi.

Lärdomar och policyrekommendationer relaterade till vinster

1. Den erforderliga bidragsnivån för stöd till utbyggnad av vindkraftverk har minskat, eftersom både den globala och inhemska förekomsten av dessa har ökat och eftersom att leveranskedjor har mognat. Det rekommenderas att Sverige förväntar sig samma utveckling under den fortsatta utbyggnaden av vindkraftverk och av andra förnybara teknologier.
2. Ett stabilt och förutsägbart bidragssystem måste införas, vilket kommer att stödja investerarnas förtroende för lång-

siktig kapitalinvestering. Sverige rekommenderas att utföra mätbara beräkningar för anpassning till alla bidragsprojekt, som svar på investerares oro för marknadsrisker och för att överdrivna och permanenta subventioner skall skapas.

3. Ett brett politiskt stöd, från flera partier, kan minimera den ”politiska risken” med den instabilitet som uppstår vid politiska förändringar inom området förnybar energi. Sverige rekommenderas att högprioritera förvaltnings- och subventionsprojekt genom en politisk konsensus som tar projektets hela livslängd i beaktande.
4. Subventioner inom ramen för subventionsprojektet i Skottland och Storbritannien har lett till högre elräkningar hos konsumenterna. Sverige rekommenderas att ta med alternativa projekt i beräkningen, i syfte att förebygga negativa fördelningseffekter, vilka kan komma att uppstå om subventionerade förnybara energikällor börjar att negativt påverka sårbara hushåll.
5. Många aspekter av förnybar elektricitet leder till miljömässiga konsekvenser: som exempel kan nämnas vattenkraftens påverkan på fisket, och vindkraftens påverkan på landskapet och koldioxidlagringens påverkan på torvmarker. Sverige rekommenderas att i samarbete med projektutvecklare, ställa höga krav på andelsägare avseende genomsynlighet och delaktighet, för att säkerställa att miljöpåverkan på lokal och nationell nivå inte blir oacceptabelt stor.
6. Det finns många betydande kostnader relaterade med vindkraftsprojekt som går utanför parametrarna för enskilda projekt, dvs. transmissionsledningar, nätstabilitet, och utjämningskrav på grund av ekonomiska oregelbundenheter. Sverige rekommenderas att fullt ut införa policys kring hur dessa kostnader skall mötas i syfte att underlätta projektplanering, utvärdering, tillståndsgivning och konstruktion.

Lärdomar och policyrekommendationer relaterade till vinster

7. Utvecklingen av den inhemska vindkraften har potential att leda till en betydande ekonomisk utveckling på landsbygden och för en nationell ekonomisk tillväxt, genom utvecklingen av en inhemsk leveranskedja. Sverige

rekommenderas att tillhandahålla ett stödjande policyramverk som underlättar för inhemska affärsföretag att delta i den expanderande vindkraftsindustrin. Sverige rekommenderas också att ge ekonomiskt stöd till kommuners förhandlingsavtal, vilka medför betydande långsiktiga ekonomiska vinster och utveckling till den lokala befolkningen.

8. De offentliga intäkterna kan utökas genom olika skatter på förnybara energikällor, bolagsskatt, företagsskatter, arbetsgivaravgifter, moms, etc. Emellertid kan detta kompenseras genom en minskning av skatteintäkter för icke-förnybara energikällor. Sverige rekommenderas att tillåta kommunerna att i större utsträckning uppbringa intäkter från de förstnämnda skatterna och avgifterna.
9. Energiprojekt på kommunnivå är ekonomiskt mindre effektiva investeringar än större kommersiella projekt, men kan direkt och indirekt tillhandahålla viktig samhällsnytta. Sverige rekommenderas att främja policys, vilka stödjer projekt för förnybara energikällor på kommunnivå.
10. Kommunernas delaktighet i planeringen av vindkraftsprojekt är avgörande i förvärvandet av en social handlingsfrihet för att kunna manövrera och minimera konflikter relaterade till utvecklingsprojekt. Sverige rekommenderas att kräva ett starkt engagemang på kommunnivå som ett sätt att minska konflikter relaterade till utvecklingsprojekt.
11. Vindkraftverk påverkar miljön, vilket har konstaterats ovan, och har både förespråkare och motståndare. Vissa människor ser dem som en positiv symbol för ren energi och kinetisk konst i landskapet, medan andra anser att de har negativa effekter, vilka förändrar landskapet och landsbygdens fysiska utseende. Den skotska regeringen och skotska kommuner har gjort betydelsefulla ansträngningar i försöken att påverka befolkningens attityder till förnybara energikällor, för att de mest ogynnsamma projekten inte skall godkännas, och för att de mest fördelaktiga projekten inte skall nekas. Sverige rekommenderas att bedriva ett liknande attitydarbete.
12. Förnybara energikällor möjliggör en minskning av externaliteter relaterade till icke-förnybara energikällor, såsom partikelutsläpp från kolförbränning och koldioxidutsläpp från både kol- och gasdrivna stationer. Även om

Sverige har en begränsad användning av fossila bränslen för elkraftsproduktion, rekommenderas kravet på produktion av förnybar el för att ersätta fossildriven elproduktion, som en prioritering för att utvinna så många miljömässiga vinster som möjligt.

13. Att använda sig av kostnads-nyttoanalyser är en kraftfull metod för att kunna jämföra vinster och kostnader med förnybar energi, både inom enskilda projekt, och inom den nationella energipolitiken. Emellertid finns det mycket osäkerhet kring framtida kostnads- och vinstflöden, vilka ekonomer har en begränsad kompetens för att kunna hantera.

Executive summary

This report is concerned with the application of cost-benefit analysis to issues of renewable energy development. We focus on experience in Scotland, a country which has experienced very rapid increases in new renewables capacity in recent years, and which has set world-leading targets for renewable energy as part of climate change and economic development policies. The effects of policy instruments used to incentivise renewable energy are outlined, and information on the wider economic consequences of renewables expansion is presented. The report explains how the environmental impacts (positive and negative) of renewable energy can be included within a cost-benefit analysis, and provides examples of studies which have estimated this environmental costs and benefits in monetary terms. Additional non-economic information is also reported on social and political costs and benefits that have occurred from the promotion of renewable energy. From this review of the Scottish experience with promoting renewables and wind farms in particular several lessons or recommendations can be learned by Sweden as they pursue similar renewable energy developments.

Lessons and Policy Recommendations Relating to Benefits

1. The level of subsidy needed to support the deployment of wind turbines is decreasing as both global and domestic experience has increased and supply chains have matured. It is recommended that Sweden expect the same as it progresses the deployment of wind farms and other renewable technologies.
2. A stable and predictable subsidy system must be put in place that will support investor confidence for long-term capital investment. It is recommended that Sweden give measured consideration to adapting any subsidy programme in response to investor concerns over market risk and creating permanent excessively high subsidies.

3. Broad based multi-party political support can minimise the "political risk" of volatile renewable energy policy shifts. It is recommended that Sweden place a high priority on managing any subsidy programme through political consensus that considers the full lifetime of the programme.
4. Renewable energy subsidies have led to increased consumer electricity bills from the subsidy programme in Scotland and the UK. It is recommended that Sweden consider complementary programmes to address adverse distributional effects if subsidised renewables start to adversely impact vulnerable households.
5. Many aspects of renewable electricity generate environmental costs: examples include hydro power impacts on fisheries, and wind farm impacts on landscapes and carbon storage on peat. It is recommended that Sweden require a high standard of transparency and engagement with stakeholders by project developers to assure acceptable environmental impacts at the local and national level are attained.
6. There are many significant costs associated with wind farms projects that are outside individual project parameters, ie transmission lines, grid stability and balancing requirements due to intermittency. It is recommended that Sweden have policies fully in place on how these costs are to be addressed in order to facilitate project planning, evaluation, permitting and construction.

Lessons and Policy Recommendations Relating to Benefits

7. Development of domestic wind energy has potential for significant rural economic development and national economic growth with the development of a domestic supply chain. It is recommended that Sweden provide a supportive policy framework that facilitates domestic business firms participating in the expanding wind industry. It is also recommended that support be given to communities negotiating agreements that bring significant long term financial benefits and development to the local population.
8. Government revenues can be increased from various taxes associated with renewables; corporate profit tax, business rates, employment taxes, sales tax or VAT, etc. However,

this may be offset with a decline in tax revenues associated with non-renewables. It is recommended that Sweden allow local governments' greater ability to capture revenues from such developments.

9. Community energy projects are less economically efficient investments than large commercial projects, but may provide significant direct and indirect social benefits. It is recommended that Sweden promote policies that support community owned renewable energy projects.
10. Community engagement in planning wind farm projects is vital to acquiring a social license to operate and minimising the conflict over development. It is recommended that Sweden require substantial community engagement as a way of decreasing conflict over developments.
11. Wind farms do impact the environment as noted above, and will be received both positively and negatively. Some people see them as a positive symbol of clean energy and kinetic art in the landscape, while others perceive them as having negative impacts that adversely change the landscape and the community. The Scottish Government and local councils have invested significant effort in attempting to balance the preferences of it population in regards to renewables so the most adverse projects do not receive consent and the most beneficial projects are not denied. It is recommended that Sweden pursue a similar balancing of concerns.
12. Renewable energy allows for a reduction in the externalities associated with non-renewable sources, such as particulate emissions from coal burning and carbon emissions from both coal and gas powered stations. Even though Sweden has limited use of fossil fuels for electric power generation it is recommended that renewably generated power be required to displace fossil-fuelled power as a priority to capture the maximum amount of environmental benefits.
13. Cost-benefit analysis is a powerful technique for comparing the benefits and costs of renewable energy at both the individual project level and the national energy policy level. However, there are many uncertainties attached to future cost and benefit flows, which economists have limited techniques for dealing with.

1 Introduction

This report is concerned with the application of cost-benefit analysis to issues of renewable energy development. We focus on experience in Scotland, a country which has experienced very rapid increases in new renewables capacity in recent years, and which has set world-leading targets for renewable energy as part of climate change and economic development policies. Renewable energy has been promoted as part of an ambitious climate change policy, which aims to reduce CO2 equivalent emissions by 80% by 2050. The Scottish Government has also seen the renewable industry as one in which it can develop a competitive advantage over the medium term, and thus as a sector which can form the focus of an economic development strategy. The effects of policy instruments used to incentivise renewable energy are outlined, and information on the wider economic consequences of renewables expansion is presented. The report explains how the environmental impacts (positive and negative) of renewable energy can be included within a cost-benefit analysis, and provides examples of studies which have estimated this environmental costs and benefits in monetary terms. The final section of the report suggests some lessons which Sweden can learn from the Scottish experience

Scotland is endowed with some of the best renewable energy resources in Europe. (Scottish Executive, 2001) These natural resources present an opportunity for global leadership in harnessing renewable energy (Scottish Government, 2008) and have resulted in the Scottish Government setting an ambitious target for renewable energy development and transition to a low carbon economy over the next 40 years. A recently-announced (October 2012) interim target aims to see 50 per cent of Scotland's electricity demand met from renewables by 2015. The Government is focused on increasing sustainable economic growth, improving economic performance, while reducing the impact on society and the environment.

1.1 International and National Policy Background

In 2008, the European Union committed to a legally binding 20% cut in greenhouse gas emissions by 2020 across all member states. (European Union, 2010) This is being delivered by the EU 20/20/20 Climate and Energy Package that requires a 20% cut in greenhouse gas emissions, 20% of energy consumption to be derived from renewable energy sources, and a 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency, all by the year 2020. Binding national targets for renewable energy will lift the average renewables share of primary energy across the EU to 20%, more than double the 9.2% attained in 2006. National targets for renewables composing a portion of primary energy range from a low renewables share of 10% in Malta to a high of 49% in Sweden. The targets will contribute to decreasing the EU's dependence on imported energy and to reducing greenhouse gas emissions. The EU has committed to strengthening the target to cut greenhouse gas emissions to 30% provided other industrialised countries commit to comparable effort and developing countries contribute adequately to global action.

Under the EU Directive on Renewable Energy, the UK has negotiated a target to source 15% of primary energy demand from renewables by 2020. Three categories of energy use are targeted to be sourced from renewables: electricity – 30%; heat – 12%; and transport fuels – 10%. (DECC, 2011) The Scottish Government committed to a new and higher target in 2011 of at least 30% of overall primary energy demand being met from renewables by 2020. This target is twice the UK's national share of the European target in percentage terms.

1.1.1 United Kingdom and Scottish Goals and Programmes

Scotland is able to pursue more ambitious goals in these matters because the Scottish Government operates as a devolved government within the United Kingdom where responsibilities are divided for various aspects of energy policy and regulation. Overall energy policy is reserved to the central UK government and covers important areas such as regulation of energy markets, international negotiation with other countries and the European Union, and international treaties on energy and climate change. Scotland can only act in an advisory role to the UK government on these matters. Scotland normally will act through domestic legislation or administrative policy to fulfil any UK determined policy or international obligation on a proportional or negotiated basis with the central government. Scotland can choose to exceed these obligations but cannot lower the objective. Energy policies that have been transferred, or devolved, to Scotland for which they have full responsibility and authority to act are energy efficiency, house-building and the promotion of renewable energy. Other devolved matters that are relevant to Scotland's experience in promoting renewable energy are: economic development; education and training; environment; agriculture, forestry and fishing; public transport particular to Scotland; and tourism.

The Climate Change (Scotland) Act 2009 introduced legislation to reduce carbon emissions by at least 80 per cent by 2050 with an intervening goal of 42% by 2020. It is hoped that this legal commitment will drive innovations in thinking, solutions, and technologies while placing Scotland at the forefront of countries working to create sustainable low carbon economies. In 2011 the Scottish Government set a goal that by 2020 the equivalent of 100 per cent of Scotland's gross annual electricity consumption would be produced by renewable energy. (Scottish Government, 2011) This ambitious goal was established with the knowledge that an intervening milestone of 31 per cent renewable electricity would be reached in 2011. Offshore wind is the principle technology that will be used to meet this goal, followed by onshore wind and to a lesser degree other renewable energy technologies like hydro, wave and tidal, and biomass.

The Scottish Government has set a goal to match that of the UK Government's which states that 11% of heat demand should be met from renewables. Currently, Scotland leads England, Wales and Northern Ireland with 2.8% of its heat demand already being met from renewable sources. The Renewable Heat Incentive Scheme (DECC, 2012) is a UK central government programme that will be implemented in 2013 to promote deployment of renewable heat technologies. The programme provides incentive payments to eligible generators of renewable heat for commercial, industrial, not for profit and public sector purposes and to producers of biomethane. The Renewable Heat Premium Payment (DECC, 2012a) scheme provides one-off financial payments to households for installation of renewable heat technologies. This scheme already operates nationwide and applies to heat pumps (ground to water, air to water or water to water) and biomass boilers. Householders who are not connected to the gas grid and currently rely on fuels such as oil, liquid gas, solid fuel or electricity for their heating can apply. Other qualifying conditions to receive the support payments are: the house must be the main home, adequate loft and wall insulation and participation in a monitoring programme to investigate the use of the heat systems. This programme will be incorporated into the Renewable Heat Incentive Scheme at some future time.

A goal for 10% of transport fuels being produced from renewable sources by 2020 has also been adopted. The Scottish Government works within the UK Government's Renewable Transport Fuel Obligation Scheme which is scheduled to reach a 5% biofuels level by April 2013. The Renewable Heat Incentive and the Renewable Transport Fuel Obligation Scheme are examples of central government climate change programmes that Scotland participates in as a regional unit of the United Kingdom in which it does not have policy independence of action.

Encouraging renewable energy production

Two primary incentive programmes exist in Scotland to encourage the deployment of renewable electricity technologies. The first, initiated in 2002, is labelled "The Renewables Obligation (Scotland)" (ROS). This is a tradable green certificate programme combined with a renewable portfolio standard, which operates in conjunction with and parallel to almost identical programmes in England, Wales and Northern Ireland.[1] The Renewables Obligation programme is being discontinued and will close to new generation projects in March 2017 and no longer operate after 2037 within the UK. It works by the government issuing green certificates for the amount of power generated to each of the renewable electricity

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[1] In England and Wales the programme is called the Renewables Obligation (RO) and in Northern Ireland the Northern Ireland Renewables Obligation (NIRO).

producers who then sell the certificates to retail power companies. The retail power companies use the green certificates to demonstrate to the government that they have met the renewable portfolio standard.

The second subsidy programme is a UK-wide feed-in-tariffs (FIT) scheme for renewable electricity. The scheme was introduced in April 2010. At this time the FIT scheme complements the ROS programme, since it only applies to small-scale renewable energy projects of less than 5 MW. The scheme guarantees a specified payment for electricity generated (over the market price) that is determined by the technology used. Both of these programmes are discussed in greater detail in Section 3.

1.2 Renewable Energy Resources

Scotland has developed a full range of renewable energy technologies. Table 1.1 below shows that four technologies are a significant portion of the total UK deployment; onshore wind, shoreline wave and tidal, small scale hydro and large scale hydro. These four areas are all dependent on the energy extracted from the natural environment or climate.

The other technologies; offshore wind, solar photovoltaics, sewage sludge digestion, municipal solid waste combustion, animal biomass, and plant biomass are all predominantly provided from within England. With two exceptions (offshore wind and solar photovoltaic) these energy sources are primarily reliant on population levels to provide waste products or the scale of the agricultural and forestry sectors. England and Wales both have superior solar irradiation levels to Scotland which improve the economics of photovoltaics.

Table 1.1 Renewable electricity capacity and generation: United Kingdom and Scotland as at 31/12/2011

	United Kingdom	Scotland	*Scottish Portion of Capacity*
Cumulative Installed Capacity[1]	**MW**	**MW**	
Onshore Wind	4,632	2,813	61%
Offshore Wind	1,838	190	10%
Shoreline wave/tidal	3	2	60%
Solar photovoltaics	1,014	56	6%
Small scale Hydro	207	149	72%
Large scale Hydro	1,453	1,321	91%
Landfill gas	1,062	113	11%
Sewage sludge digestion	203	8	4%
Municipal solid waste combustion	504	11	2%
Animal Biomass[2]	161	21	13%
Plant Biomass[3]	1,074	111	10%
Total	**12,152**	**4,796**	**39%**

[1] Cumulative capacity at the end of the quarter/year.

[2] Includes the use of farm waste digestion, poultry litter and meat and bone.

[3] Includes the use of waste tyres, straw combustion, short rotation coppice and hospital waste.

Source: DUKES (2012).

Table 1.2 Renewable electricity capacity and generation: Scotland

Generation[4]	**Scotland (GWh)**
Wind[5]	2,555
Shoreline wawe/tidal & Solar PV[5]	6
Hydro[5]	1,892
Landfill gas[5]	144
Sewage sludge digestion[5]	5
Other biomass (inc. co-firing)[5,6]	189
Total	**4,790**

[4] Generation figures for the latest quarter of 2011 are highly provisional, particulary for the thermal renewable technologies (such as landfill gas) in the lower half of the table.

[5] Actual generation figures are given where available, but otherwise are estimated using a typical load factor or the design load factor, where known.

[6] Includes co-firing, plant biomass, animal biomass and biodegradable part of municipal solid waste.

Source: DUKES (2012).

Scotland has significant seasonal variation in provision of renewable energy due to higher levels of wind and rainfall in the winter months as compared to spring and summer months. See Table 1.3.

Table 1.3 Quarterly Load Factors[2] for renewable energy sources in Scotland:

Load Factors	2011	2011	2011	2011
	1st quarter	2nd quarter	3rd quarter	4th quarter
Wind	55%	28%	19%	39%
Hydro	76%	34%	35%	58%
Landfill gas	55%	55%	56%	58%
Sewage sludge digestion	46%	28%	29%	26%
Days in quarter	90	91	92	92

Load factors are calculated based on installed capacity at the beginning and the end of the quarter/year.
Source: DUKES (2012).

We now provide more detail on each of the main renewable technologies being deployed.

1.2.1 Offshore Wind

There are 568 installed offshore wind turbines in United Kingdom waters, totalling 1,858 MW, and a further 665 turbines in construction, totalling 2,359 MW. The total number of operational turbines and those under construction is 1,233. (RenewableUK, 2012)

Only 190 MW of this capacity is located in Scotland at two wind farms. One farm is a demonstrator test site that consists of two 5 MW turbines in the Moray Firth. The other wind farm is the 180 MW Robin Rigg site that has 60 turbines that are 3 MW each at a height of 125 metres that began operation in April 2010. An additional technology testing and demonstration wind farm has been granted construction consent for a single 7 MW turbine, while 2 wind farms totalling 1,000 MW have formally entered the Scottish and UK Government's planning and consent process. See Map 1 below.

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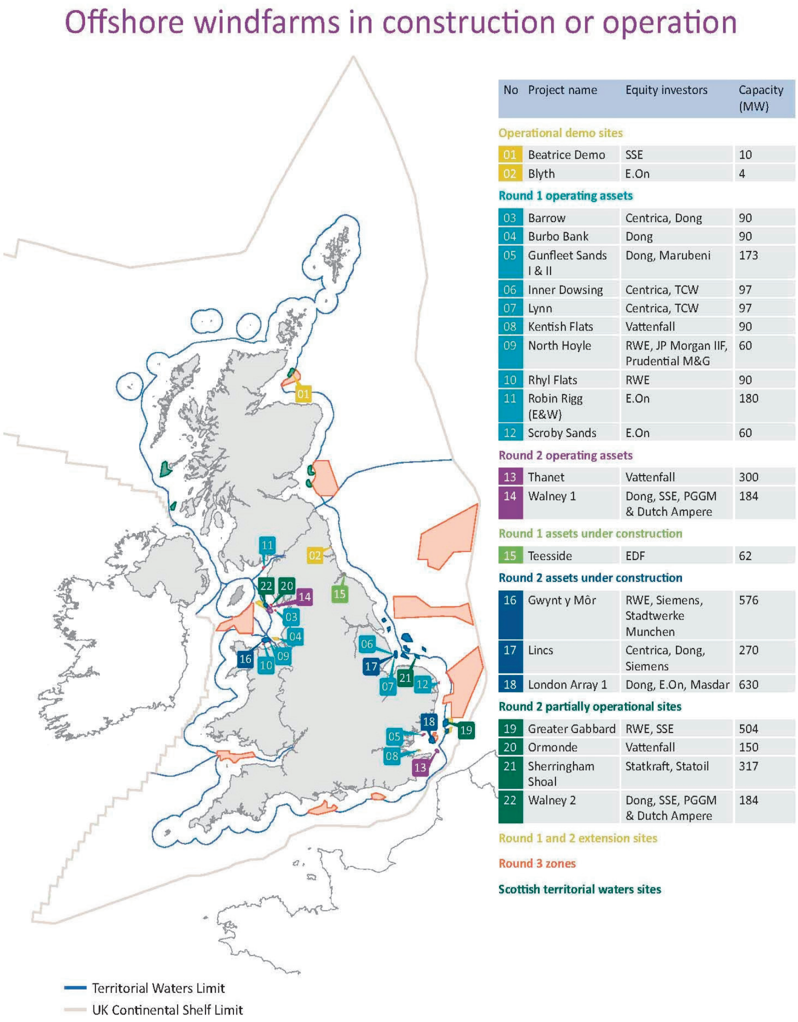
[2] Load factor is a ratio of the actual amount of energy produced during a period of time divided by the maximum energy that could have been produced (e.g. a 2MW wind turbine can generate 17,520 MWh of electricity a year with ideal wind conditions but actually produces 4,500MWh of electricity during a year, thus having a load factor of 25.7%).

Map 1 Offshore wind farms in construction or operation in UK waters



Offshore windfarms in construction or operation

No	Project name	Equity investors	Capacity (MW)
Operational demo sites			
01	Beatrice Demo	SSE	10
02	Blyth	E.On	4
Round 1 operating assets			
03	Barrow	Centrica, Dong	90
04	Burbo Bank	Dong	90
05	Gunfleet Sands I & II	Dong, Marubeni	173
06	Inner Dowsing	Centrica, TCW	97
07	Lynn	Centrica, TCW	97
08	Kentish Flats	Vattenfall	90
09	North Hoyle	RWE, JP Morgan IIF, Prudential M&G	60
10	Rhyl Flats	RWE	90
11	Robin Rigg (E&W)	E.On	180
12	Scroby Sands	E.On	60
Round 2 operating assets			
13	Thanet	Vattenfall	300
14	Walney 1	Dong, SSE, PGGM & Dutch Ampere	184
Round 1 assets under construction			
15	Teesside	EDF	62
Round 2 assets under construction			
16	Gwynt y Môr	RWE, Siemens, Stadtwerke Munchen	576
17	Lincs	Centrica, Dong, Siemens	270
18	London Array 1	Dong, E.On, Masdar	630
Round 2 partially operational sites			
19	Greater Gabbard	RWE, SSE	504
20	Ormonde	Vattenfall	150
21	Sherringham Shoal	Statkraft, Statoil	317
22	Walney 2	Dong, SSE, PGGM & Dutch Ampere	184
Round 1 and 2 extension sites			
Round 3 zones			
Scottish territorial waters sites			

Source: Crown Estate (2011) UK Offshore Wind Report 2011

The Crown Estate is the responsible UK government agency that manages the seabed for non-hydrocarbon commercial usage.

(Crown Estate, 2011)[3] Nine offshore wind farm zones of varying sizes were identified within UK waters. Renewable energy developers were asked to bid for exclusive rights to develop offshore wind farms within the zones. The successful development partners for each zone were announced in January 2010. The Crown Estates is acting as co-developers and partial owner of each of these projects up to the point of project consent and are contributing significant funding for the early stage planning and development studies. In excess of £100 million has been contributed to date.

The Crown Estate awarded seven exclusivity agreements in 2009 to wind farm developers for zones that have been deemed appropriate for offshore wind development. Five zones are located within 12 nautical miles of Scottish shores and have a total authorized capacity of 4,845 MW. Two further offshore zones have been licensed for development; both are located beyond the 12 nautical mile limit and outside Scottish Territorial Waters. These two development zones are within the Renewable Energy Zone[4] and are designated by reference to the UK Continental Shelf Exclusive Economic Zone. See Map 1 above. The two zones have an additional authorized capacity of 4,765 MW, giving a combined total of 9,610 MW of wind energy generation capacity. Table 4 lists the names and MW capacity of the individual leases.

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[3] The Department for Energy and Climate Change (DECC) manages offshore hydrocarbons commercialisation.

[4] The Renewable Energy Zone was declared under section 84 of the Energy Act 2004. It extends up to a maximum of 200 nautical miles from the shore baseline. The UK has claimed exclusive rights in this area with respect to production of energy from water or winds.

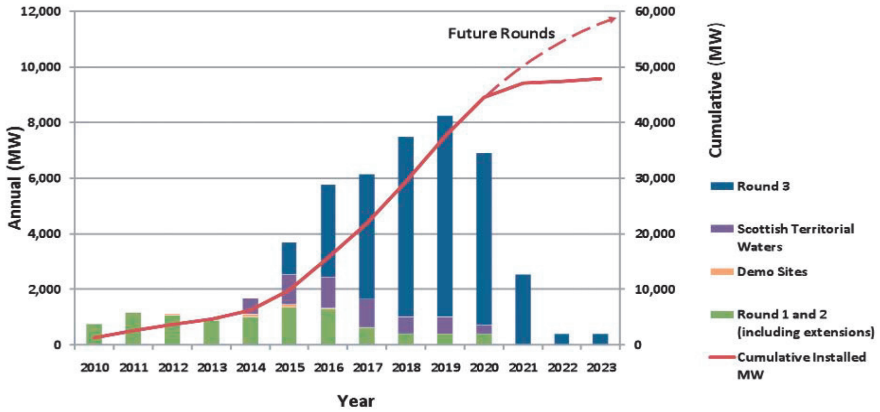
Table 1.4 offshore wind

Scottish Territory Waters Leasing Road 2009	
Zone	*MW Capacity*
Argyll Array	1,800
Beatrice	1,000
Inch Cape	905
Islay	680
Neart na Gaothe	450
Total Capacity	**4,845**
Round Three Leasing Offshore Wind Zones Started 2008	
Zone	*MW Capacity*
Firth of Forth	3,465
Moray Firth	1,300
Total Capacity	**4,765**
Combined Total	**9,610**

Source: The Crown Estate, 2011

There is the potential for 48,000 MW of offshore wind capacity to be built in the next fifteen years if all leases grant by The Crown Estate are fully developed. See Graph 1 below

Figure 1.1 Opportunity for generating capacity from all current leasing rounds in UK waters



Source: The Crown Estate, UK Offshore Wind Report 2011.

The scale of the offshore wind energy development represents a large and significant opportunity for sustainable economic growth in Scotland. Accordingly, the Scottish Government has identified several challenges that they consider crucial for further deployment of offshore renewables. (Scottish Government, 2011)

The cost and financing of capital – Market mechanisms must continue to drive investment - Electricity Market Reform currently under consultation by the UK government is critical for further development of the sector. The recommended reforms are discussed further in Section 3. The creation of a Green Investment Bank to facilitate project financing has been completed with offices in London and Edinburgh. Greater market competition that drives technological advancement and lowers costs is required as there are currently a limited number of proven offshore wind turbine suppliers. The Crown Estate has leased two offshore demonstration sites in Scotland which are actively seeking planning and consent. One onshore site, located adjacent to the shoreline, is being developed for offshore turbine testing. These sites are to facilitate innovation and development of new offshore turbine technology in Scotland. Capital cost, and it’s financing, is seen as the most import issue in deploying cost effective renewables.

Planning and regulation – Efforts must continue at the streamlining of planning and consent processes for marine renewables by Marine Scotland, the responsible Scottish Directorate for integrated management of Scotland's seas. In particular efforts to establish a practical method to evaluate environmental impacts are required, also additional evaluation procedures to address development proposals within the inter-tidal zone, onshore elements of offshore proposals. It is imperative to continue a research programme on the interactions between offshore wind developments and the natural environment to ensure the planning and consenting processes are fully informed. Cooperation and coordination with The Crown Estate for additional offshore leasing rounds for continued expansion.

Grid access – There is a shortage of grid access onshore for some of the offshore zones. Economic incentives need to be created to motivate appropriate development of both onshore and offshore transmission networks.(OFGEM, 2012; OFGEM, 2011) Currently, the Scottish Government believes that proposed transmission charging regimes disproportionately penalize renewable energy project that are a long distance from electricity consumers, specifically Scottish generation being transmitted demand centres in southern England.

Skills – There is a potential for a shortage of skilled workers as the renewables sector expands by up to 40,000 additional jobs during the next decade. This increased employment is dependent on significant manufacturing and construction services for offshore renewables being located within Scotland. A skills development plan (SDS, 2011) is being implemented by the Scottish Government that identifies the route to providing the required skills, which includes a realignment of the higher education sector to ensure that the necessary courses are available.

Supply chain development – It is important that supply chain development continues to be supported and expands to provide the commercial resources for marine renewables deployment. Scottish businesses are in position to support, participate and benefit from this sectors potential multi-£billion expansion. A key role for the Scottish Government and its development agencies in taking forward the National Renewables Infrastructure Plan (Scottish Enterprise, 2011) is to advise and connect relevant companies with the opportunities that exist - from device and foundation design, manufacture and installation to electrical design and cabling provision / installation.

Innovation and R & D – There is an on-going need to improve the technology and operational methods for offshore deployment. Key issues that need further innovation are: reliability, survivability, installation techniques, and anchoring. Additional onshore and offshore testing facilities are also needed. The Government's Enterprise Agencies will be working to bring in inward investment and to grow Scottish companies.

Public engagement – There needs to be continued expansion and strengthening of public engagement in the development process. It is believed by the Scottish Government that renewable energy targets cannot be met in the face of significant public opposition. However, the necessary support of the Scottish public can be gained through early and meaningful engagement that consider public and community views on commercial schemes, and access to benefits - including the scope to develop community-owned schemes.

Key actions that the Scottish Government plans to pursue:

- Maintain market incentives at a level that significant investment continues in offshore wind through the Renewables Obligation and it possible replacement.
- Investment in infrastructure from which projects and turbines can be manufactured, launched and serviced. A dedicated £70 million National Renewables Infrastructure Fund has been established to leverage private sector investment into important facilities, in particular harbours and ports.
- Support for innovation as cost reduction for offshore technology is vital to the economic viability and risk reduction of projects.
- Grid transmission charging and infrastructure financing must be modified to promote the deployment of offshore renewables, not act as a barrier to development.

The strategic goals of the Scottish Government as given in their policy paper for offshore wind development are (Scottish Government, 2011a):

- Maximise the contribution that offshore wind energy makes to renewable energy generation in Scotland;
- Maximise opportunities for economic development, investment and employment;
- Minimise adverse effects on people, other economic sectors and the environment; and
- Deliver offshore wind while complementing other forms of marine energy generation.

1.2.2 Onshore Wind

There are 322 operating onshore wind farms in the United Kingdom, totalling 4,756 MW, with a further 1,436 MW of capacities under construction and due for commissioning in 2012/2013.

Scotland has 2,981 MW of onshore wind power capacity which accounts for 63% of the UK total. An additional 1,083 MW is under construction in 24 wind farms, which is 75% of all UK construction. A further 113 wind farms with 2,481 MW of capacity have been consented but are not yet under construction. 4,261 MW of capacity have formally applied for planning permission and are awaiting final determination. In excess of 4,000 MW capacities are in an early stage process and have requested pre-application opinions from local governments.

A portion of these consented but not yet built projects are delayed waiting for sufficient expansion of the electrical transmission network. In particular, the Beauly to Denny transmission line that will connect projects located in the north of Scotland to transmission lines located in central Scotland is a major source of delayed construction. The proposed upgraded transmission line was delayed for three years in the planning process as the project creates a major visual impact through some scenic landscapes that was controversial among stakeholders. The project was approved in 2010.

Scotland's onshore wind resource has provided a high average annual load factor compared to other European countries and countries that have deployed large quantities of wind turbines[5], but it has also suffered from cyclical weather patterns that have caused the annual load factor to vary significantly, as can be seen in Table 1.5. This annual variation in wind effects the UK annual load factor as well, see Graph 2.

Table 1.5 Onshore Wind Generation Load Factor – Scotland 2008 -2011

Year	2008	2009	2010	2011
Load Factor	29%	27%	21%	35%

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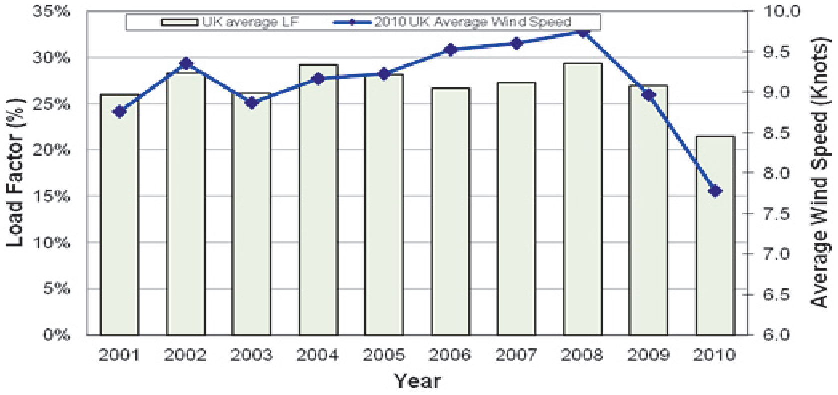
[5] China has an expected national average load factor of ~23%. (REEEP, 2007).

Figure 1.2 **Annual variation in load factor on an unchanged configuration basis and wind speed, 2010**



Source: DECC – Regional Renewable Statistics, 2011.

The scale of the onshore wind energy development represents the creation of a new industrial sector in Scotland and continues to offer considerable opportunity for sustainable economic growth in Scotland. Accordingly, the Scottish Government has identified several crucial challenges to deployment of onshore renewables in its 2020 Routemap for Renewable Energy. (Scottish Government, 2011)

Financial support of renewables – the uncertainty about future support for onshore wind caused by the wide ranging review of the electricity markets by the UK Government has the potential to hold back investment decisions as industry loses confidence in the longevity and level of support. What the UK Government does could have profound implications for the development of onshore wind in Scotland.

Secure grid access - Lack of grid access in areas of high resource still an issue. Sector and stakeholders can overcome some of these issues by working in partnership, but key challenge in this area lies in the timescale for grid upgrades and refining the approach to grid investment and charging issues.

Public engagement – Public acceptance issue around environmental impacts and benefits for local communities. Related issue around extent of genuine community engagement and benefit from onshore wind farms.

The Government's general commitment is to provide appropriate financial support mechanisms in conjunction with a cooperative planning system which provides a clear spatial and policy direction, continues to engage local communities, and balances protecting the environment with progress to meeting the recently increased renewable electricity targets.

Key actions the Scottish Government plans to pursue in support of continued onshore wind energy development are:

- Maintain effective market support for onshore wind, both through the ROS and its possible replacement and the FIT that provides support for smaller wind farms up to 5 MW in capacity. Specifically, in context of the Electricity Market Reform proposals from the UK Government that have introduced uncertainty for investors. Any reforms must combine to deliver a coherent and effective level of support.
- Advocate for a less punitive outcome from the review of grid regulation and charging issues. The existing charging regime is a barrier to development; its satisfactory and timely resolution will play a vital role in developing the sector.
- Encourage local planning authorities to produce spatial planning frameworks that are transparent and provide clarity for developers. Investigate long-term solutions to technical challenges involving aviation, noise, proximity to communities, cumulative impacts in the landscape and to encourage best practice for developer using lessons from the Good Practice Wind project. (GPWind, 2010)
- Promote early stage and on-going community engagement so that local stakeholders impacted by onshore wind projects are fully aware of what is proposed and the benefits that could be provided. Promote increased level of benefits delivery to impacted communities. (Scottish Government, 2010)

Actions already taken by the Scottish Government to provide for continued onshore wind development and increased public support:

- Requirements have been created that proposed projects demonstrate carbon saving potential to ensure that any wind farms which get built provide real carbon savings as well as renewable electricity. This is particularly relevant to sites located on peat lands, as carbon stored in peat is lost when wind farms are being built, so as to influence design and build plans to optimise carbon benefits.

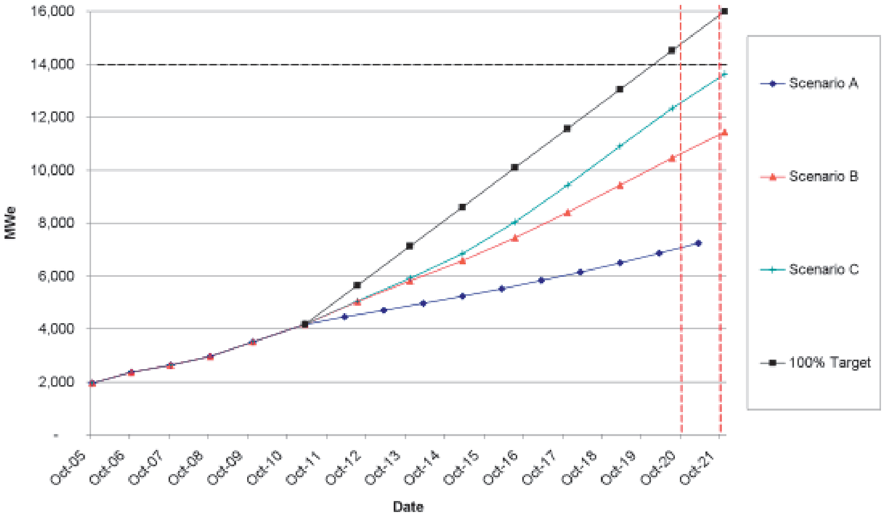
- Barriers have been removed to community ownership of renewable projects through the launch of the Community and Renewable Energy Scheme loan fund. (CES, 2012)
- Streamlining the planning system has continued with the consolidation into a single document of the various documents which previously formed the Scottish Planning Policy. Centralised planning advice on a range of renewable energy technologies was launched as an online resource, giving greater scope to keep pace with the frequent changes in the renewables sector, particularly in terms of new technologies, innovations, new national policy initiatives, targets, incentives and planning practice.
- Requirements that the National Forest Estate, under management of the Forestry Commission Scotland, streamline its procedures for leasing land for renewable energy development including a mandatory requirement that local communities receive a payment of at least £5,000 per megawatt of installed capacity per annum from the developer.

1.3 Potential Deployment Trajectories

The graph below demonstrates projections of potential patterns of deployment of renewable electricity capacity in Scotland, based on historical trends, with variables such as the speed of the planning system or the success of the Electricity Market Reform in matching Scottish ambitions.

The deployment of renewable electricity capacity depends on a number of complex and interdependent factors and as such these scenarios represent feasible but ultimately uncertain deployment profiles driven by the assumptions adopted.

Figure 1.3 Projections of Renewable Electricity Installed Capacity Based on Historical Data



Source: 2020 Routemap for Renewable Energy in Scotland.

The scenarios modelled in the chart above represent (Scottish Government, 2011):

A. Deployment projection based upon an extrapolation of the annual deployment levels experienced in 2007-08.

B. Deployment projection based upon an extrapolation of the annual deployment levels experienced between 2009 and the start of 2011.

C. Deployment projection, based on Scenario B above, adjusted for the improvements in the planning/consent system that were introduced in recent years but which have not yet impacted upon actual deployment rates.

D. The 100% target line is a straight line extrapolation between current installed capacity and the estimated levels of capacity required to achieve 100% of gross consumption from renewables in 2020. This hypothetical line is incorporated to identify and acknowledge the scale of the challenge. In reality, it is recognised that deployment will not follow a straight line and would be expected to accelerate towards the latter part of the decade, particularly given the potential magnitude of offshore wind deployment.

Each of the modelled scenarios places the ambition of the Scottish Government in the context of the very successful levels of deployment seen in recent years. The successful delivery of the capacity required to deliver the equivalent of 100% of Scottish electricity consumption will demand a significant and sustained improvement over the deployment levels seen historically.

1.4 Basic Economics of Wind Energy

There have been three dominant trends (EWEA, 2009) that have impacted the economics of commercial scale grid connected wind turbines during the past 20 years; turbine size has increased, turbine efficiency has improved, and investment costs decreased and then became volatile. The size of turbines has increased in both height and MW capacity. The first commercial onshore wind farm in the UK was commissioned in 1991 and used 400 kW turbines. By 2005 the average size was slightly less than 2 MW and turbines of 3.6 MW capacity have been deployed in wind farms constructed during 2010-2011. (RenewablesUK, 2012)

Offshore wind turbines have increased in size and capacity even faster than onshore. In 2000 the first offshore wind farm using 2 MW turbines was built and grid connected in Europe, while the average size of turbines grid connected during 2011 was 3.6 MW up from 3 MW in 2010. The first 5 MW turbines were used in 2007 at Beatrice in the UK and 2008 at Hooksiel in Germany, with a greater than 5 MW turbine being deployed at Ormonde in the UK during 2011. The Siemens 3.6 MW is being used extensively throughout the world for projects currently being constructed. However, 5 MW – 6 MW turbines are being deployed for some projects. (EWEA, 2012).Turbine efficiency has increased as taller structures were designed to capture faster winds that occur at higher elevations. Improved siting of farms and more efficient and reliable components also increased the effectiveness of the technology. Overall an efficiency increase of 2 - 3% per annum was experienced since the middle 1990's.

Investment costs decreased throughout the 1990's and into the early part of the past decade. Reduction of costs by swept rotor area (kWh/m2), a measure of the physical size of the turbine, have declined by 30%, or around 3% per year from 1989-2001. However, during the 2000's the installed costs of both onshore and offshore wind turbines has become more volatile, with prices both escalating significantly and falling. Factors other than improvements in technology and manufacturing have come to dominate the cost structure.

Two major contributing factors to the increased costs of deploying wind farms were the increased demand for turbines and the increases in the costs of raw materials from which to manufacture the turbines. With the global economic boom there was increased competition from other industrial sectors for both raw materials and high skill labour. For numerous reasons, ranging from climate change obligations to energy security nations around the world pursued expansion plans for renewable energy sources like wind energy. This later factor is a simple economic case of demand increasing faster than supply of a product which resulted in a higher market price. Recent price declines have occurred for the same reasons, only in reverse. The global economic downturn has led to less competition for resources of both material and labour, so manufacturing costs have declined. And the expansion of Chinese turbine manufacturing capabilities, with their associated lower costs, has increased the supply, while the global financial problems have reduced purchases of turbines and balance of plant equipment. In addition, competitiveness among supplies to the market has resulted in lower market prices.

1.4.1 Direct and Indirect Costs of a Wind Farm

Key factors (Blanco, 2009) that determine the cost of generating electric power with wind turbines are:

Investment in physical capital – this is composed of wind turbines and the balance of plant components such as foundations, road construction, and grid connection with all the requisite engineering design, consultancy, licensing, and permitting, etc. These costs can account for approximately 80%[6] of the total costs of a wind farm project. RenewablesUK (2010) reported that installed costs for onshore wind farms constructed in 2009-2010 ranged from £1.25million/MW to £1.573million/MW, with a weighted average of £1.334million/MW. A range of £2million/MW

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[6] Note that values throughout the discussion of wind farm costs are only indicative and that considerable variation can occur between individual projects depending on such factors as the project being onshore or offshore, distance to grid connection, road access, depth of water, etc.

to £4million/MW installation costs for UK offshore wind has been reported for the few wind projects that have been completed in the UK. A weighted average of approximately £3.1million/MW reflects offshore costs in 2010 which is comparable to other projects in European waters. (RenewablesUK, 2011)

Variable costs of operation – this is composed of the operation and maintenance of wind turbines, land rental, insurance and taxes, management and administration. Note that the cost of fuel is not incurred by wind farms which can amount to 40% - 80% of the costs of operating a gas or coal-fired power plant. Variable costs can account for approximately 20% of the total costs of an onshore wind farm project. The costs of offshore operation and maintenance can be expected to be double that of onshore. (RenewablesUK, 2010)

Generation capacity factor – the amount of electricity a wind farm produces is dependent on the specific project location, technical specifications of the wind turbine, and site characteristics. The capacity factor of a power plant is the ratio of the actual output of a power plant over a period of time and its potential output if it had operated at full capacity the entire time. There is a direct relationship to the quality of the wind farms location, i.e. wind speed, hours of duration, and the total marketable electricity that can be produced. Scottish wind farms had an average capacity of 28.1% from 2000 to 2010, as compared to England's average capacity of 24.6%. The UK wide capacity for offshore wind was 30.5% in 2010. Capacity factors are the single most important factor in determining the potential profitability.

Economics project life and discount rate – combined these two factors show the perceived risk for the project, the investment climate, the regulatory stability, and the available alternative investments. The project life of a turbine for cost recovery purposes is commonly assumed to be 20 years. Discount rates range from 5% - 10% depending on the ratio of equity financing and debt financing for onshore projects.

Indirect Costs of a Wind Farm

There are other costs created by the deployment of wind farms that are not directly related to the actual project and the project developer may or may not be responsible for paying. Wind farms are generally connected to the local distribution network or to the high voltage transmission grid. Infrastructure must be constructed to allow for this interconnection and the safe operation of the wind farm as a part of the overall electricity network in a country. Who is responsible for these costs can have a significant impact on project financial viability and on general electricity tariffs in a country. The main costs are transmission lines and system balancing costs due to the intermittency of power generation by wind farms.

Wind farms are typically located away from urban areas in remote rural lands, which are not well served by network transmission lines. A new 210 km transmission line being built to transmit electricity produced by wind farms in the north of Scotland to central Scotland is estimated to cost £600 million. Even short connections of a few miles to connect a wind farm can cost several million pounds sterling.

The electricity system must be maintained in constant balance with the amount of electricity being generated being exactly equal to the amount of electricity being consumed. The independent system operator who oversees the network and is responsible for the balancing the system typically imposes financial penalties on generators that do not deliver power as contracted. Thus wind generated electricity will incur higher balancing costs as other dispatchable generators are required to increase production when wind resources are not available or curtail production when wind resource are in excess of forecast. The major implication of this is that excess generating capacity must be provided to produce electricity when wind farms are not generating.

1.4.2 Experience Curve and Learning Rates to Lower Manufacturing Costs

Historically, renewable energy technologies have not been cost competitive in open free markets and therefore have not been deployed except when conventional power sources have been unavailable or too expensive to provide. One of the indirect objectives of government programmes to increase the quantity of deployed wind turbines is to lower the cost through accelerating the experience curve or learning rate[7] of design, manufacture, and installation. Learning rates are commonly expressed as the percentage of cost reduction for each doubling of cumulative MW of deployed wind turbines. Learning rates for onshore wind farms have been estimated to be around 10% per doubling over the past 20 years (The Carbon Trust, 2008), while Junginger (2005) found a range of 15% to 23% in a meta-study. Other related industries that wind farm developers rely upon, such as construction and HVDC electricity distribution, have shown learning rates between 5% and 32%. It should be noted that recent academic critiques of learning curve research has called in to question the robustness of estimated effects and the impact on lowering costs. (Klaassen, et al, 2005; Söderholm and Sundqvist, 2007) There needs to be caution when using these estimated learning rates and predicting cost reductions. Distinct learning occurs at different levels in the wind industry, globally versus nationally or regionally. (Lindman and Soderholm, 2012) So there will be two distinct learning paths that determine how fast costs decline, the global rate of expansion having a larger impact then the national rate. Scotland and the UK should expect more modest learning rates than the rates reported above.

Cost reductions of both onshore and offshore wind turbines can be the result of standardisation of key components, improvements in manufacturing technology and processes, more efficient onsite construction and assembly procedures, and introduction of improved turbine access methods in the case of offshore wind turbines which can enable quicker repairs to turbines and improved reliability.

There is debate over the validity of learning rates for the wind energy industry because many of the forecasted cost reductions have not been reached. (RenewablesUK, 2011) Part of the reason overly optimistic costs reductions has been that the wind energy industry has adopted technologies and skills from other industries that are already mature and have attained lower costs through experience therefore leaving less room for improvements. One example of this is the transfer of experiences in the onshore wind sector to offshore wind development.

Given the relatively large total deployed capacity of onshore wind technology to this date, it may take a decade to complete two doublings and incorporate the subsequent learning and costs

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[7] Experience curves and learning rates are essentially the same concept and are used interchangeably in this paper.

improvements. If the majority of offshore wind capacity that has been licensed by The Crown Estate is developed in the next ten years cumulative capacity will reach approximately 48,000 MW in UK waters. This equates to over four doublings in the next decade.

1.5 The Rest of this Report

In what follows, we will (i) review the basic approach of Cost-Benefit Analysis, as a technique for conducting policy- and project-level evaluations of renewable energy options; (ii) describe the evidence base on the private, financial costs of renewable energy, based on Scottish experience to date; (iii) review the evidence on the financial and other economic benefits of renewable energy, again based on Scottish experience, and then (iv) explain how the environmental impacts of renewables, both positive and negative, can be included into cost-benefit analysis, and what the evidence is to date on the scale of environmental benefits and costs. Section 6 concludes, and asks what Sweden can learn from the Scottish experience with aggressively promoting renewable energy as a key element of energy and climate policies. Full references can be found at the end of the report.

The report is written assuming a minimal background in economics, and so should be easily accessible to all interested in the appraisal of renewable energy options.

2 Cost-Benefit Analysis: principles and methods

2.1 What is Cost-Benefit Analysis?

In essence, the idea behind Cost Benefit Analysis (CBA) is very simple. It is a technique for measuring whether the benefits of a particular action are bigger than the costs, judged from the viewpoint of society as a whole. By an "action", we mean a deliberate decision to commit resources, which may involve two broad types:

- Deciding on whether to introduce or reform a particular government *policy*, such as introducing a new energy tax; or
- Deciding on whether to go ahead with a particular investment *project*, such as a new motorway or hydroelectric scheme.

To assess either type of decision using CBA, the analyst adds up the benefits of the project or policy and compares them with the costs. If the benefits are indeed bigger than the costs, then the project or policy makes society better off as a whole. If the costs are bigger than the benefits, then society is worse off as a whole if the project or policy goes ahead. To begin with, we present an overview of how a cost-benefit analysis is conducted, so that the reader is aware of how the method can be used.

CBA can be used to investigate the economic efficiency of particular projects, such as a new wind farm, but also the effects of changes in policy – for example, increasing the target level of electricity supply to be met by renewables. CBA provides information on who gains and who loses (faces costs) as a result of a project or policy, and how these costs and benefits are distributed over time. It is also a useful way of simply presenting the impacts of a project approval or policy decision, and if applied widely can ensure consistency in public policy-making.

Let us take as an example a decision over whether to allow a new hydro-electric power scheme to be constructed in Sweden. The CBA method involves six stages of analysis:

i) Project/policy definition.

This involves setting out exactly what is being analysed; whose welfare is being considered; and over what time period. The CBA is this example is concerned with a new hydroelectric plant at a particular location, involving the building of access roads and a dam, the flooding of a valley, and the consequent generation of electricity, but a decision must be made about whether linked, ancillary investments (such as new transmission lines) should be considered as well. In terms of "whose welfare", the usual answer is that it is national well-being that is considered, that is, all impacts are defined in terms of effects on people living within Sweden. The analysis is to be carried out over the expected life time of the plant, say 30 years. Often, defining the "relevant population" is a difficult issue. For instance, if the dam would threaten an internationally-rare habitat, should the costs to foreign conservationists also be counted? The relevant time period may also be problematic. If nuclear waste storage proposals are being analysed, then it is necessary to make allowance for the very long half life of some radioactive wastes.

ii) Identify physical impacts of the policy/project

Any project/policy has implications for resource allocation: in this case, labour used to build access roads; additional electricity production due to the creation of a new power station; land used up in the creation of the reservoir; less pollution being generated from a coal fired power station which can now be closed early. The next stage of a CBA is to identify these outcomes in physical magnitudes: so many hours of labour, so many megawatt hours of electricity, so many hectares of land. For environmental impacts, Environmental Impact Analysis will often be used to produce predictions. Frequently, these changes in resource allocation will not be known with certainty – for example, how many tonnes of pollution will be displaced? How many hours of the year will the power station operate for? For environmental impacts, uncertainty in outcomes is to be expected to an even greater degree than with other impacts. The effects on invertebrate fauna from a reduction in acid deposition, or the effects of enhanced global warming on species migration are examples.

Once physical impacts have been identified and quantified, it is then necessary to ask which of them are relevant to the CBA. Essentially, anything which impacts on the quantity or quality of resources, or on their price, may be said to be relevant, if these impacts can be traced back to a link to the well-being of the relevant population. Since we specify relevant impacts in terms of utility impacts, it is not necessary to restrict attention to market-valued impacts, since non-market value changes (such as an improvement in air quality) are relevant, if they affect peoples' utility.

iii) Valuing impacts

One important feature of CBA is that all relevant effects are expressed in monetary values, so that they can then be aggregated. The general principle of monetary valuation in CBA is to value impacts in terms of their marginal social cost or marginal social benefit. 'Social' here means "evaluated with regard to the economy as a whole". Simple financial investment appraisal, in contrast, values costs and benefits in terms of their impact on firms and their shareholders only. But where are these marginal social benefits and costs derived from? Under certain conditions, this information is contained in market prices. Market prices contain information on both the value to consumers of a particular product (say electricity) being supplied, and the costs to producers of supplying it. The market wage rate, similarly, shows both the value of labour to employers and the value of leisure to workers. Assuming that the impacts of the project are not large enough to actually change these prices, then market prices are a good first approximation to the marginal values of benefits and costs (Sugden and Williams, 1978). Where markets work well, market prices and market supply and demand curves contain useful information about social costs and benefits of more electricity produced, or more land being used up.

But markets often "fail", for example when the actions of private firms and households imposes costs on others, for example when pollution from a coal fired power station harms the health of those living nearby. Moreover, for some "goods" like biodiversity and river water quality, no market exists at all from which a price can be observed. In such cases, market prices are no longer a good guide to social costs and benefits. Section 2.4 explains how in principle this valuation problem can be solved in CBA,

iv) Discounting of Cost and Benefit Flows

Once all relevant cost and benefit flows that can be expressed in monetary amounts have been so expressed, it is necessary to convert them all into *present value* (PV) terms. This necessity arises out of the time value of money, or time preference. To take a simple example, suppose an individual is asked to choose between receiving £100 today and receiving that same £100 in one year's time. The more immediate sum might be preferred due to impatience (I want to spend the money right now). Alternatively, I may not want to spend the money for a year, but if I have it now I can invest it in a bank at an interest rate of say 10%, and have £100 x (1+i) = £110 in one years time, where i is the rate of interest. The motives for time preference, and reasons for discounting, are briefly discussed in section 2.6 below: for now, all that need be recognised is that a sum of money, and indeed most kinds of benefit, are more highly valued the sooner they are received. Similarly, a sum of money to be paid out, or any kind of cost, seems less onerous the further away in time we have to bear it. A bill of £1 million to re-package hazardous wastes seems preferable if paid in 100 years' time rather than in 10 years' time. This is nothing to do with inflation, but more to do with the expectation that we might expect to be better off in the future, or to be able to pass the bill onto future generations.

So how is this time effect taken into account, and how are cost and benefit flows made comparable regardless of when they occur? The answer is that all cost and benefit flows are *discounted*, using a discount rate which, for now, is assumed to be the rate of interest, i. The present value of a cost or benefit (X) received in time t is typically calculated as follows:

$$PV\ (X_t) = X_t\ [(1 + i)^{-t}] \qquad (2.1)$$

The expression in square brackets in equation (2.1) is known as a discount factor. Discount factors have the property that they always lie between 0 and +1. The further away in time a cost or benefit occurs (the higher the value of *t*), the lower the discount factor. The higher the discount rate *i* for a given *t*, the lower the discount factor, since a higher discount rate means a greater preference for things now rather than later.

Discounting may be done in CBA in one of two ways: either by finding the net value of benefits minus costs for each year and discounting each of these annual net benefit flows throughout the lifetime of the project; or by calculating discounted values for each benefit or cost flow, and then summing these discounted benefits and costs. For example, adding up total discounted labour costs, total discounted material costs and total discounted energy saving benefits.

(v) Applying the Net Present Value Test

The main purpose of CBA is to help select projects and policies which are efficient in terms of their use of resources. The criterion applied is the *Net Present Value* (NPV) test. This simply asks whether the sum of discounted gains ($\Sigma B_t(1 + i)^{-t}$ as it is written below) exceeds the sum of discounted losses (written as $\Sigma C_t(1 + i)^{-t}$). If so, the project can be said to represent an efficient shift in resource allocation, given the data used in the CBA. The NPV of a project is thus:

$$NPV = \Sigma B_t(1+i)^{-t} - \Sigma C_t(1+i)^{-t} \qquad (2.2)$$

where the summations Σ run from $t=0$ (the first year of the project) to $t=T$ (the last year of the project). Note that no costs or benefits before year 0 are counted. The criterion for project acceptance is: accept if $NPV > 0$ (ie is positive). Based on the criterion explained in the next section, any project passing the NPV test is deemed to be an improvement in social welfare.

An alternative way of thinking about the NPV criterion is in terms of a Benefit-Cost Ratio. This is simply the ratio of discounted benefits to discounted costs. The decision rule becomes: proceed if and only if the benefit-cost ratio exceeds unity.

(vi) Sensitivity Analysis

The NPV test described above tells us about the relative efficiency of a given project, given the data input to the calculations. If this data changes, then clearly the results of the NPV test will change too. But why should data change? The main reason concerns uncertainty. In many cases where CBA is used, the analyst must make predictions concerning future physical flows (for example, the quantity of electricity produced per year) and future relative values (for example, the wholesale price of electricity). None of these predictions can be made with perfect foresight. When environmental impacts are involved, this uncertainty may be even more widespread. An essential final stage therefore of any CBA is to conduct sensitivity analysis. This means recalculating NPV when the values of certain key parameters are changed. Following Johansson and Kristrom (2011), a more sophisticated approach is to assume that each parameter follows a distribution and to then take repeated draws from this distribution for each variable (eg for ouput prices, for input costs..). For each draw, a NPV can be calculated, leading to distribution of NPVs, which can then be presented to decision-makers.

2.2 Why is CBA useful?

In one very important sense, the practice of CBA addresses what might be called the fundamental economic problem: how to allocate scarce resources in the face of unlimited demands. Using scarce resources such as land or capital in one way imposes an opportunity cost on society, in that we cannot use those same resources for some other purpose. CBA allows the decision analyst to compare competing uses of scarce resources in terms of the relative net return to society.

Not only does CBA allow a comparison of the benefits and costs of particular actions, reflecting therein the scarcity of resources, but it also allows for ordinary peoples' *preferences* to be included in government decision-making. As section 2.5 makes clear, economic values in a CBA depend partly on what people like (their preferences), what they are prepared to give up to have more of what they like (their willingness to pay) and what they can afford to pay (their budget constraint). In a sense, CBA is an exercise in economic democracy, since every citizen gets an economic vote in terms of their willingness to pay. The strength of votes is constrained by resources –by people's incomes – which may seem unfair – and is influenced by their knowledge and understanding of the likely benefits and costs (MacMillan et al, 2006). Nevertheless, CBA is a formal way of setting out the impacts of a project or policy over time, of organising debate over an issue, and of identifying who enjoys the gains and who suffers the losses from such undertakings. It is also, as Arrow et al (1998) have noted, a good way of ensuring consistency and perhaps transparency in public-sector decision making. As a procedure which must be gone through for policy decisions or project funding to be approved, CBA has merits in that in this "gatekeeper" role it helps enforce an agreed set of principles in how decision-making should be undertaken over time.

However, it is also important to be aware that undertaking a CBA can itself be a costly exercise in terms of time and staff resources. Many benefits and costs, particularly those relating to environmental, non-market impacts, can be very hard and expensive to estimate. Moreover, uncertainty will always characterise the flow of costs and benefits in the future if a project is actually implemented. Policy managers need to thus make a judgement about whether a particular decision warrants a full CBA, or perhaps a more back-of-the-envelope ("quick and dirty") CBA. Qualitative CBA analysis, which might simply list main benefits and costs, and who gains or loses from implementation, can also be useful to aid decision-making, and can be done simply and cheaply. Policy managers also need to be aware of the limitations of CBA, as outlined in this section (see Hanley and Barber (2009) for more details).

2.3 A brief theoretical background

2.3.1 Valuing gains and losses

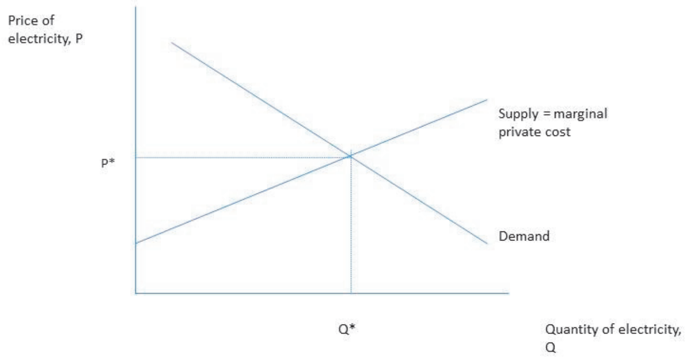
CBA is about comparing the gains and losses (benefits and costs) of undertaking a new project or policy. But how to measure these gains and losses? One fundamental requirement is that all gains and losses thought to be relevant are measured in the same units, otherwise they cannot be added together (aggregated), either across people or over time. The unit of measurement in CBA is money, but the conceptual basis is utility. Utility is a term used by economists to represent those factors which make people happy, or which explain people's choices. Ideally, CBA would evaluate gains and losses by adding up positive and negative changes in utility across individuals. However, for many years, economists have known that utility is difficult to translate into a cardinal measure.

To obtain a cardinal measure – a "how much" measure - which approximates an underlying utility change we use *money metrics* of underlying utility change, in particular either the most that someone is *willing to pay* to acquire more of something desirable, or less of something undesirable; and the least that someone is *willing to accept* in compensation for giving up something desirable, or tolerating something undesirable. This means that we can use an individual's maximum Willingness to Pay (WTP from now on) as a measure of what an increase in the quantity of something good is worth to him. WTP measures both the intensity of preferences (how much I like something) and the direction of preferences (do I prefer more or less of something). Similarly, if a project will increase road noise Jill hears whilst sitting in her garden, then her minimum Willingness to Accept compensation (WTA) for this decrease in her utility tells us what peace and quiet is worth to her – or rather, what the proposed change in peace and quiet will "cost" her in terms of lost utility.

2.3.2 Market prices versus shadow prices

Imagine a proposal to construct a new wind farm in Southern Sweden, the output of electricity from which would not be big enough to change the market price of electricity; and whose demand for inputs (say labour for construction) would not be big enough to change the market price of these inputs (in this case, the wage rate for construction workers). Consider now the market for electricity. The new wind farm will generate say 10 megawatt hours of power per year. In Figure 2.1, we show the market for electricity in Sweden. The demand curve shows how much consumers are willing to buy at different prices: it also shows how much they value each extra unit of electricity supplied. This marginal willingness to pay declines as the quantity supplied increases. The supply curve shows the marginal costs of producing electricity from the many competing power sources around the country, and reflects the opportunity costs of the scarce resources which are used up in electricity production. The electricity market is in equilibrium when demand equals supply, at price p^*. At this price, the marginal willingness to pay of customers just equals the marginal costs to producers of supplying electricity. If there are no external costs or benefits of electricity production (this is explained below), then the market price measures both what consumers are WTP at the margin for one more unit of electricity, and the costs of producers of supplying this unit – their minimum WTA (supply price) for producing this quantity. So marginal WTP can be measured, along with marginal WTA, by simply consulting the market price.

Figure 2.1



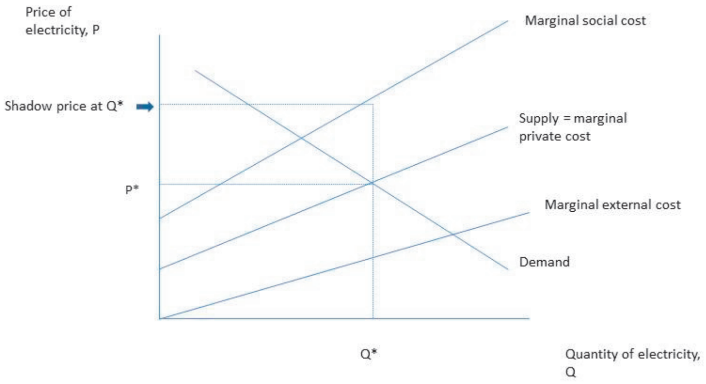
However, what we wish to measure in CBA is the *social* costs and benefits of an action, that is the costs and benefits to all members of society. In many cases, social and private costs, and social and private benefits, are the same thing, meaning that the market price tells us both marginal social and marginal private costs and benefits (recall that we have assumed no effects of the project on prices at the present). However, there are important instances where this does not hold. Economists refer to some of these instances as "market failure" (Hanley, Shogren and White, 2006). Take for example the production of electricity. If electricity is produced from coal or oil or gas, then burning these fuels will result in pollution from sulphur dioxide, nitrous oxides, particulates and CO2. Take the example of particulates. These can have adverse effects on human health for people living close to the plant. Yet the costs of these pollution impacts do not fall on the private company generating the electricity – they are "paid" by sufferers with chest complaints. Hydro electric production can have adverse impacts on salmon fisheries, by hindering fish migration. These costs do not fall on the hydro company, but on fishermen who are deprived of the opportunity to fish. Carbon emissions from fossil fuel power stations contribute to global climate change which may have adverse effects on people living in flood-prone areas of countries many thousands of miles away from the power station. Flooding a valley to create a new hydro-electric scheme likely means that the biodiversity and recreation benefits associated with the valley are lost forever – what is known as an irreversibility in economics – although of course the lake created by the dam may generate offsetting recreation and amenity benefits. Such irreversible environmental costs can also be included in the CBA.

Pollution is an example of the *external costs* referred to above: a cost which does not fall on (is not paid by) the agent responsible for causing it. In Figure 2.2, we show the same supply curve (= marginal *private* cost curve) for a competitive energy industry, and the demand curve for electricity. The market price is again at p^*. But now we also include a *marginal external cost* curve: this shows the marginal value of damages associated with emissions and other environmental impacts from electricity generation, which increase as a result of rising production. From society's point of view – and thus from the viewpoint of CBA – the relevant costs to consider are the social costs or *shadow price* of production, that is the <u>sum</u> of marginal private costs and marginal external costs. As can be seen, the market price no longer provides a guide to this value. This means that using the market price of energy to value electricity output would overstate social benefits of increased electricity output, unless we also include in the analysis the external costs that result from this production. For a proposed expansion of electricity output above Q^*, then the social costs at the margin of this expansion include both the costs to the firm and the external costs. As can be seen, an expansion of electricity output above Q^* would actually fail a CBA test, since the marginal social benefits (shown by the demand curve) are less than the marginal social costs.

A parallel concept to that of external costs is that of external benefits, and these constitute another reason why market prices can be a poor guide to marginal social costs or benefits. An external benefit results when production activities result in benefits which are not valued by the market, or which are additional to those valued by the market. For example, a decision by a private forest owner to protect old-growth forest from felling will produce external benefits in terms of the value of the associated biodiversity change for society. This external benefit would be added to the value of forests in a CBA.

The incorporation of both external benefits and external costs into a CBA is a reflection that the market price does not tell the analyst all of the costs and benefits of change in activity, when there are “missing markets”. But another case which needs to be considered is where a market price exists, but where this market price is in some sense, wrong. CBA practionners have used the terminology of *shadow pricing* to refer to the case where market prices need to be adjusted to turn them into a better guide to marginal social benefits or costs. Missing markets are one reason for shadow pricing being necessary, such as with external benefits and costs. Another reason for shadow pricing is government intervention in markets.

Figure 2.2



2.3.3 Valuing price changes

Government intervention can have big effects on the prices paid by consumers and those received by producers. Two examples relate to climate change policy. By imposing a tax on carbon dioxide emissions, governments increase the price that households pay for travelling by car, or for heating their houses. By subsidising renewable energy investments through a higher “feed-in” tariff for green electricity, governments can change the price that renewable producers receive for their output. How should we value those changes within a CBA? The answer is that we apply the general principals laid out above. For a price rise, we can ask: “what is the most that consumers are willing to pay to avoid this”, or “how much compensation would we need to give consumers to maintain their utility levels?”. We can also ask: what is the most that a firm would be “willing to pay” to benefit from higher prices? What is the compensation they would need to make up for prices not rising? Symmetrical questions can be posed for price reductions. In both cases, the analyst will calculate the changes in consumers’ and producers’ surplus resulting from price changes – these are the relevant values for inclusion in the CBA when prices change.

2.3.4 Measuring net changes in aggregate social well-being – the Kaldor Hicks compensation test.

The Kaldor Hicks test examines whether a project or policy brings about a “Potential Pareto Improvement”. This means that those who would be better off as a result of the project are willing to pay more, in aggregate, to have the project go ahead, than those who would be worse off from the project would demand in compensation to allow it to occur. In other words, where the maximum aggregate WTP of the gainers (the social benefit) is greater than the aggregate minimum WTA of the losers (the social cost). Note that no compensation is actually paid to losers: we simply ask whether the gainers *could* compensate the losers, and still be better off.

Some implications which need to be highlighted from adoption of the Potential Pareto Improvement criterion are as follows:

- Social values are determined by the sum of individuals’ values, and nothing else
- Individuals’ valuations of the effects on them of a prospective project are the most appropriate measures of the costs or benefits to them
- Losses and gains are symmetrical, in the sense that a loss to one individual can be offset against a gain to another
- All losses can be compensated for.

Clearly, these are controversial statements in some peoples’ eyes. There is a literature which argues that citizen and collective values should also be considered, not just the values people place on things as individual consumers (see the references in Alvarez-

Farizo et al, 2007). Individuals may not understand all the impacts of a project (for example, if it involves a change in biodiversity), or may want things that are "bad for them", leading to notions of liberal paternalism; willingness to accept compensation for a loss of an environmental benefit is likely to be (much) greater than willingness to pay for an equivalent gain (Bush et al, 2012), yet CBA can treat these two measures symmetrically; whilst evidence from stated preference studies suggest that some people refuse monetary compensation for environmental losses (Spash and Hanley, 1995).

Implementing the Kaldor-Hicks test consists of adding up the benefits of a project across all those who will gain, and then comparing this aggregate sum of benefits with the aggregate sum of costs. The analyst thus adds up the real resource benefits of the project (the value of electricity generated by a new wind energy investment, the value of displaced carbon emissions) and compares it with the real resource costs of the project (the market price of steel and concrete used in construction, the opportunity cost of land, the environmental impacts on birds, the loss in utility to those who feel that landscape quality is diminished). In this sense, the "adding up" is being done at the level of the project as a whole, broken down into benefits and costs. In this treatment, "transfer payments" – such as taxes paid to the government on profits made, or subsidies offered by the government to the wind energy company – cancel out of the analysis, and so are ignored. So if the wind energy company receives a £1 million subsidy from the government, the CBA analysis would not include this as a benefit, since this equate to a £1 million cost to taxpayers. At the level of the economy as a whole, no net real cost or benefit occurs.

An alternative way of aggregating gains and losses is to divide the population into interest groups who are likely to be effected by the project: for example, taxpayers, electricity consumers, bird watchers, and the power company. Gains and losses can be added at the level of each group, and the net social benefit is then the sum of the changes across groups. In this treatment, transfer payments appear in the analysis, since they are gains to some groups, and losses to others. But when we add up gains and losses across groups, transfers they cancel out, so that this way of presenting the CBA should give the same result as the "real resource costs and benefits" approach outlined in the previous paragraph. An advantage of the "by interest group" approach, in contrast, is that gains and losses are clearly set out according to whom they accrue to: this may give more insight into the likely acceptability of the project, or of any compensation schemes that might need to be taken account of.

2.4 Valuing costs and benefits under uncertainty

This short section addresses a fundamental problem in undertaking a CBA: that the analyst is not certain about the benefits and costs which will result from undertaking a project or policy. For example, planting a new forest, where timber production is the main expected benefit, will result in uncertain future benefits since we cannot be sure about the world timber price in 30 years time. Creating a new wetland as a means of preventing storm surges and reducing flooding will have uncertain benefits since future weather patterns are unknown. Investing in wave energy will result in uncertain benefits since the future demand for electricity is not known for sure, and since the cost evolution over time of alternative renewable sources is hard to predict. Costs can also be uncertain, for instance the cost of generating nuclear power will depend on what happens to uranium prices over the next 20 years, and how decommissioning and waste treatment technologies evolve.

A discussion of uncertainty is helped by distinguishing between *states of the world* and *probabilities of occurrence*. States of the world mean just that – future conditions for prices, costs, technologies, weather patterns and health impacts which are possible. For instance, a prediction for annual winter rainfall in Sweden in 2030 is that, relative to 2008, it could be (i) the same (ii) 5% higher (ii) 20% higher. These are alternative states of the world. A second type of useful information is the likelihood of these different states of the world occurring. For example, climate modellers might be able to say that state (i) has a 25% chance of occurring, state (ii) a 55% chance of occurring and state (iii) a 20% chance. If these states-of-the-world are the only possible outcomes (unlikely!), then their probabilities must sum to 1, and we could compute an *expected* value for winter rainfall in 2030 which is equal to:

Expected winter rainfall in 2030 = (0.25. (state i) + 0.55. (state ii) + 0.20 (state iii))

More generally, if it is possible to identify all possible outcomes for a variable, X_i, and the chance with which they will occur at some point in the future – or over some interval – then this means that the probability distraction of X is known, and the expected value of X is given by:

$$\sum_{i=1}^{n} Xi.Pi \tag{2.3}$$

which shows that the expected value is a mean value computed over all possible outcomes, weighted by their probability of occurring.

Analysts typically identify two kinds of uncertainty in CBA. The first is where all possible states of the world are known along with their probability distribution. This means an expected value for the variable can be calculated. In practice, the analyst more likely knows some of the more likely future outcomes (eg for weather, for timber, for uranium prices) and their likelihood of occurring. Where might this information on probability distributions come from? From statistical analysis of past trends in variables, and modelling of future possible outcomes. Such situations, where both states of the world and probability distributions are know, is referred to as *choice under risk*. Alternatively, the probability distributions may be unknown, and/or many possible states of the world unknown. This situation is referred to as *Knightian uncertainty*, named after the economist Frank Knight.

Where future states of the world can be identified along with their probability distributions – that is, for choice under risk - the expected costs and/or benefits can be calculated using the formula shown in (2.3). However, it should be noted that this implies that gainers and losers are equally concerned with outcomes which are higher than and lower than the expected outcome. Moreover, it assumes *risk neutrality*, that is, that people would be indifferent between a bet with an expected value of $V and receiving $V for sure. This does not describe many people! Individuals are typically assumed to be risk-averse, in that they would require a larger expected value say ($V+v), to be indifferent between receiving this and a sum $V for sure. In this case, the idea of *certainty-equivalence* has been suggested, whereby the analyst would seek to identify those values for a future risky benefit or cost which gainers or losers would be indifferent between, in terms of receiving this risky outcome and a lower future benefit/cost for sure.

Where outcomes are uncertain in the Knightian sense, then expected values cannot be calculated, since the probability distributions and/or states of the world are unknown. In this case – and indeed, in the majority of cases in applied CBA - then the main "solution" to the problem is sensitivity analysis. This means recalculating the Net Present Value (NPV) when the values of certain key parameters are changed.

2.5 Valuing "non-market" benefits and costs

The natural environment provides a multitude of vital goods and services to the economy and to the world's citizens. However, market failure – in particular, missing markets due to the absence of a complete and enforceable system of property rights for environmental resources - means that in many, many cases, environmental values are not revealed by the market. So, if a policy will threaten biodiversity in Brazil, there is no market price of "biodiversity services" which we can consult to inform our CBA of such a policy. If a new policy on forest management in Sweden will result in water pollution increasing, then again there is no market price of pollution which can be consulted.

In developing these environmental valuation methods, it is useful to think of a two-way classification for how environmental resources generate economic value. This involves a consideration of *direct* and *indirect* environmental values. Direct environmental values arise when an environmental resource impacts directly on people's well-being. For example, if we think about the value of improving water quality on a river. Some benefits will come about in terms of people who directly use the river, say for kayaking or swimming. These benefits are expressed then through direct changes in utility; river water quality appears as a variable in people's utility functions:

$$U = U(\mathbf{X}, Z, W) \qquad (2.4)$$

where $\mathbf{X}$ is a vector of market-valued goods and services, W is river water quality and Z are other environmental resources about which an individual cares. In this sense, an improvement in water quality has a direct benefit since it impacts *directly* on utility.

But imagine that water is also abstracted from the river as one input to the production of beer, and that beer is one item (good X_1) within the vector **X** in (2.6), as the production function in (2.7) shows:

$$Q_{x1} = Q\,(L, K, W) \tag{2.5}$$

Here, water quality W is an input to the production of beer (x_1), along with labour (L) and capital (K). If an improvement in water quality reduces the costs of producing beer since water treatment costs fall, then this reduction in the price of beer means that the environmental quality change has produced an *indirect* value for people, though its role as input to production. Many environmental services function in this way, for instance the role of wetlands in supporting coastal fisheries, or the role of rainfall and soils in crop production. Valuation methods can then be divided into whether they focus on the environment as a direct source of utility (eg contingent valuation), or whether they model the environment as an input to production (eg dose-response models), and as thus contributing indirect values.

A finer classification can also be made with regard to direct approaches to valuation. Impacts on the utility function from a change in environmental quality are measured conceptually using WTP and WTA, as we saw above. *Stated Preference Methods*, such as contingent valuation, use carefully constructed questionnaires to estimate these WTP and WTA amounts from individuals for a given environmental change. Alternatively, direct utility values can be estimated using *Revealed Preference Methods*, which examine people's behaviour in markets related to the environmental good in question, and infer WTP and WTA from this behaviour. The travel cost model and the hedonic price method are examples of revealed preference approaches. Indirect methods, on the other hand, study environmental values through the role of the environment as an input to production. Such methods are classified in this report as *Production Function Methods*. The analyst can also ask what costs are avoided by conserving an ecosystem; for instance, the costs of flood control which are avoided if a coastal wetland is retained, or the avoided costs of controlling particulate pollution if investment in renewable energy allows a replacement of fossil fuel powered electricity generation. This approach is known as the *Avoided Costs* method.

Many textbooks review these non-market valuation methods in detail, so we do not take up space here in repeating this (see, for example Haab and McConnell, 2002). Instead, Table 2.1 summarises the methods, and illustrates what kind of environmental impacts from renewable energy can be costed with each. Later in this report, section 5 contains detailed summaries of a number of key studies using these methods.

Table 2.1 shows that a wide variety of environmental impacts from renewable energy can be "costed" and brought within the monetary balancing of a CBA. This includes both favourable effects (displaced SO2 or CO2 pollution from burning less fossil fuel to generate electricity) and unfavourable effects (such as damage to recreational salmon fishing and landscape impacts which are judged undesirable by some). All of the valuation methods which environmental economists have developed since the mid 1970s have a potential role to play.

2.6 A brief discussion on discounting

Almost all investments in renewable energy involve benefits and costs which occur over a period of many years. For instance, a new wind farm may take 2 years to construct, and will then generate electricity over a 15-year period before significant replacement work is needed on turbines. A biomass plant, generating electricity from burning agricultural and household waste, will also generate power and heat over a number of years. Similarly, construction of a new hydro electric dam may take 3 years, but then power is produced for 50 years. Applying economic analysis to such projects, or to policies which effect the likelihood of such projects being undertaken, involves the comparison of benefits and costs which occur at different times in the future. Even once the effects of inflation have been corrected for by converting nominal monetary flows into real (constant-price) flows, society weights benefits and costs differently according to how far in the future they occur. The further into the future a give benefit or cost occurs, the lower the weight people place on this as judged from the present. Why? For individuals, *positive time preference* has been attributed to:

3 Impatience: people prefer benefits now to later

4 That as people get older, they typically get better off; as our income or wealth rises, the marginal value of one more Krone of benefit falls;
5 Fear of death: as we get older, the chance we will be around to enjoy future benefits falls;
6 Risk: the further into the future a benefit or cost is forecast to occur, the less sure we are about this actually happening.

For society as a whole, a similar argument can be made, since what society wants is, on one view, simply the aggregation of what individuals want. Societies (economies) get richer over time due to economic growth, whilst the rate at which each dollar of additional income adds to society's utility is declining. Societies are composed of impatient people, so that the government economist should weight near-future benefits higher than far-future benefits. For a fuller discussion of what the discount rate should be, and how it should be applied, see Dasgupta (2008) and Weitzman (2007).

Table 2.1 Relevance of non-market valuation methods to impacts of renewables

Method	Type of impact	Example
DIRECT METHODS *Stated preferences*		
Contingent Valuation	Effects of hydro power on recreational salmon fishing; landscape impacts or wildlife impacts of new windfarm	Willingness to pay on part of fishermen to restore salmon fishing in a damned river
Choice Experiments	Landscape effects of windfarms; relative environmental impacts of micro-generation versus large scale wind	Negative impacts of off-shore wind farms according to distance from shoreline and size of wind farm
Revealed Preferences		
Travel cost models	Impacts on recreational fisheries and tourism.	Costs in terms of loss in consumers surplus to recreational fishermen of new hydro scheme
Hedonic pricing	Landscape effects of waste incineration and off-shore wind farms	Impacts on coastal house prices of new off- shore windfarms. Effects of new transmissions network on house prices
INDIRECT METHODS		
Production function approach	Health benefits of displaced pollution from coal plants; impacts on coastal fisheries of new tidal power scheme	Loss of inter-tidal mudflats in terms of productivity of coastal fisheries. Avoided morbidity from less particulates.
Avoided costs	Carbon loss from peatlands due to windfarm construction; air pollution from biomass plants; displaced CO2 emissions from gas plants.	Use of ETS carbon price or government floor price for carbon dioxide to value losses of stored carbon from erosion of peatlands due to windfarm construction; use of SO2 marginal abatement costs to value reductions in SO2 emissions

2.7 Cost-Benefit Analysis and Renewable Energy Projects: a brief history

As several authors have made clear (eg Banzhaf, 2008), the practice of CBA in government developed in the specific context of renewable energy, as a means of assessing public spending and public policy on the construction of new dams in the USA during the 1960s. Conceptually, decisions over renewable energy are very amenable to analysis using CBA, since there is an initial investment, followed by a stream of benefits and costs over time; and since a social perspective on these benefits and costs, rather than a private one, is relevant to public sector policy analysis. Some of the advances in methods for non-market valuation were also made in the context of renewable energy issues, for example with regard to existence values for species threatened by hydro-electric projects. As section 5 shows, many non-market valuation studies have been undertaken in Europe and the US on the environmental impacts of renewable energy. However, despite all of this, it is not clear that there are any *recent* examples of public policy making in either Europe or the US over renewable energy where CBA has been decisive. Instead, this report suggests that CBA be considered as one useful source of information for public policy choice over renewables in Sweden.

2.8 Conclusions

This section has explained why economists believe cost-benefit analysis (CBA) to be a useful tool for project and policy analysis; and has explained the methods of CBA as applied to renewable energy. To re-state, CBA is useful for policy and project analysis since it enables a systematic quantification and comparison of the main impacts of proceeding; since it shows who gains and who loses from a decision; and since it shows the time pattern of these impacts. CBA can applied to individual renewable energy projects to assess their economic efficiency, but also to a set of possible projects (such as windfarm construction at 6 possible locations), and used to rank these on benefit-cost criteria. CBA can be used to compare investments in different forms of renewable energy (eg off-shore versus on-shore wind), as well as investments at different locations. As noted at the start of the section, CBA can also be used to assess the benefits and costs of possible revisions to energy policy, such as setting a more ambitious target for total renewable energy as a fraction of all energy consumed/produced in a country, or to compare different policy instruments for achieving a given target (such as comparing green certificates with feed-in tariffs).

3 Private Economic Costs

3.1 Introduction

All economic activities incur costs as well as create benefits. If the economic benefits are greater than the costs in an open market than private enterprise is expected to engage in the business activity. Renewable electricity generation technologies have mixed results when comparing private, market-valued costs versus benefits. Some renewable technologies, like large scale hydroelectric schemes and energy-from-waste power plants, typically have positive net benefits while others have significant net costs. Wind turbines and all the associated costs of deploying wind farms have seen considerable cost improvements during the past two decades but are generally still in need of additional support measures to be financially viable. Currently the best onshore wind farms in the world produce power as economically as coal and gas, whilst average onshore wind farms are forecasted to be cost competitive with some conventional power sources by 2016. (Bloomberg, 2011) Offshore wind needs major advances in turbine technologies and development/deployment experience before it will be close to competitive in the next 10-15 years or longer. Many renewable technologies would thus operate at a loss in a free market system at present. Since governments frequently have policy objectives to increases renewable supply as a percentage of all electricity consumption, they are thus required to make use of a range of policies to enable private firms to make a profit from investing in renewables. Such measures are aimed at either increasing the revenues or decreasing the financial costs of investing in and operating renewable energy installations.

This chapter discusses costs that are associated with the markets for renewable energy generation in general and wind energy systems in particular. The structure of this chapter starts with a discussion of the types of markets that facilitate and incentivise the development and deployment of renewable energy technology. The future of renewable energy markets in Great Britain is considered with a brief overview of the energy market reform that has recently been proposed. It is followed by a discussion of the two major government programmes to promote deployment, and then a review of some of the indirect costs associated with renewables.

3.2 Market structures for renewable energy

Cost of electricity from RE sources versus traditional energy sources

The cost of electricity varies depending on the generation technology being used. The majority of renewable and low-carbon technologies are more costly to produce energy. The costs indicated in the tables below do not include external costs such as environmental damage or ancillary services that may be required for the technology to be integrated into the transmission network.

The costs charged to consumers will reflect a weighted average of the portfolio mix of a particular electricity supplier. A mix of technologies is commonly used be a supplier to provide security of physical supply and as a hedge against price volatility. Some renewables are especially effective as a price hedge as the “fuel input” is freely provided by nature. However, in general terms, renewable generation assets demand a large capital investment to construct and therefore have little opportunity to have lower costs of production once built. Conventional power plants, gas and coal, can experience lower costs if the cost of fuel decreases.

This point is particularly relevant as the global availability of natural gas supplies increase from the expanded use of shale gas extraction methods; with this increased supply, the market price of gas has dramatically fallen in North America and may fall in Europe and other parts of the world as well. The potential impact in the UK is that natural gas fuelled power plants may provide lower cost electricity that is also lower in carbon pollution in comparison to coal. If this occurs the relative costs of renewable electricity will become disadvantaged.

The principle monetary value that policymakers and stakeholders use to compare between different generating technologies is the levelised cost of energy (LCOE) figure. This cost is often cited as a convenient summary measure of the overall competiveness of different technologies. LCOE represents a per-megawatt hour cost that would apply for the complete project life. It is the present value of the total cost of building and operating a generating plant over an assumed financial life and duty cycle, converted to equal annual payments and expressed in terms of real dollars to remove the impact of inflation. (EIA, 2012) LCOE reflects overnight capital costs, fixed and variable operating and maintenance costs, fuel cost, financing costs, and an assumed utilisation rate for each technology and facility type. The availability of additional incentives like tax credits or other tax instruments can also impact the calculation of levelised cost. The LCOE values used throughout this report do not incorporate any such incentives unless explicitly stated.

Table 3.1 Levelised Cost of Electricity for Various Low-Carbon Technologies

Low Carbon Technology	Levelised Costs (£/MWh)
Projects Started in 2011	
Onshore 5MW>	£90.20
Onshore <5MW	£104.90
Offshore Round 2	£121.60
Offshore Round 3	£147.50
Dedicated Biomass >50MW	£144.60
Dedicated Biomass 5-50MW	£127.60
Cofiring Conventional	£96.70
Energy from Waste	-£30.80
Energy from Waste CHP	-£29.50
Hydropower 0-5MW	£130.60
Hydropower 5-16MW	£72.60
Anaerobic Digestion 0-5MW	£105.20
Anaerobic Digestion CHP	£82.60
Sewage Gas	£82.20
Landfill Gas	£44.20
Biomass CHP	£134.80
Projects Started in 2017	
Onshore 5MW>	£87.50
Offshore Round 2	£105.70
Offshore Round 3	£122.40

Source: DECC (2011a)

There are two categories of low-carbon technologies that have lower costs than conventional power sources; energy from waste and landfill gas. The energy from waste technologies have a negative levelised cost as a result of the fuel (waste) having an avoided cost of disposal attached to it; in essence a waste to energy plant is paid to take the fuel. The other cost to note is that both onshore and offshore wind with turbines 5MW> will be cost competitive with many forms of coal power production in the coming decade.

Table 3.2 Levelised Cost of Electricity for Various Nuclear or Fossil-fuelled Technologies

Technology	Levelised Costs
Projects Started in 2009	
Gas CCGT	£79.70 - £80.30
Gas CCGT with CCS	£111.40 -
FOAK	£112.50
Nuclear PWR FOAK	£97.10-£99.00
	£102.20-
ASC Coal	$104.5
ASC Coal with CCS FOAK	£136.20 -
FOAK	$142.10
	£131.20 -
Coal IGCC FOAK	£134.60
Coal IGCC with CCS	£143.00-
FOAK	£147.60

ASC – Advanced supercritical coal; CCGT – Combined cycle gas turbine; CCS – Carbon capture and storage; FOAK – First of a kind to be built; IGCC – Integrated gasification combined cycle; PWR – Pressurised water reactor. .

Source: Mott MacDonald (2010)

Social Impacts

The impact on domestic electricity bills of changes in the generation portfolio is of concern on a social level, as any increase in energy costs negatively impacts the poor disproportionately more than other social groups. Domestic space heating in Scotland accounts for 58% of all domestic energy consumption and is essential during autumn and winter. There are serious health implications if a residence in not kept warm enough, with an estimated 2,700 deaths related to energy poverty in the UK each year. (Hills, 2012)

A household is said to be fuel poor if it needs to spend more than 10 per cent of its income on fuel to maintain an adequate level of warmth which is usually defined as 21 degrees for the main living area, and 18 degrees for other occupied rooms. Modelled fuel costs in the definition of fuel poverty extend beyond heating and also include heating water, lights and appliance usage and cooking costs. The Scottish House Condition Survey - Key Findings 2009 estimated that for every 5% rise in energy prices, all else being equal, a further 46,000 households move into fuel poverty. (EAS-NEA, 2011) At the end of 2010 there were approximately 658,000 fuel poor households in Scotland. (SCHS, 2011) As a proportion of the total households Scotland is significantly more affected than England. See Table 3.3 below.

Table 3.3 Proportion of Households in Fuel Poverty

Country	Proportion of households that are fuel poor	Year of estimate
England	16.40%	2010
Scotland	27.90%	2010
Wales	26.20%	2008
Northern Ireland	43.70%	2009
UK	18.60%	2010

Source: DECC (2012d) Annual Report on Fuel Poverty Statistics 2012

3.2.2 General types of markets instruments or structures to support RE deployment: Research & Development

Funding support for research, development and demonstration is necessary to stimulate the development and market uptake of renewable energy technologies that are far from commercial scale deployment. R&D funding has two primary sources – state public funds and private venture/entrepreneurial capital. Early private investment capital tends to come in two forms; small venture firms that are pursuing a specific niche technology innovation, or large corporations. Government sourced R&D funding is common at the national level throughout the EU member states. The EU has additional short, medium and long term research programmes for different technologies. The objective of technology development is to increase the competitiveness of renewable technologies through decreased investment or production costs.

> *The Scottish Government has a programme of R&D funding that will offer financial support for projects that have the potential to reduce the cost of producing energy from offshore wind farms. (Scottish Enterprise, 2012) The European Offshore Wind Deployment Centre is being developed by Aberdeen Offshore Wind Farm Ltd (AOWFL), comprising current partners Vattenfall Wind Power UK , Technip and Aberdeen*

There are two major reasons why governments should support or subsidise R&D in renewables. The first is to meet government targets for reduced greenhouse gas emissions in a cost effective manner. By assisting private firms or government research laboratories in developing more efficient renewables technologies the private cost as well as the social cost of creating a low-carbon economy can be reduced. The other is the public good[8] nature of R&D. Increased knowledge about renewables technology will help all parties in their research activities. Acemoglu, et al, (2012) argues that from a theory point of view, optimal climate policy requires both a carbon tax and a temporary R&D subsidy for clean energy technology.

This economic rationale for government support of R&D is tied to the presence of "market failures" associated with R&D activities. The relevant market failures are investment risk and imperfect appropriability of benefits derived from the research activity. Imperfect appropriability, or the diffusion of knowledge, implies that the private rate of return to R&D is lower than its social return. This results in private business under- investing in research activities which are therefore likely to be below the socially optimal level. The investment risk associated with research requires a risk premium in the rate of return. Public financial markets are often averse to fund R&D projects in new technologies, which is especially detrimental to new entrants and to small firms that are constrained financially. Government support of R&D aims to reduce these market failures. (Guellec and Potterie, 1997)

Governments can support the R&D process in various ways. Framework conditions such as funding necessary infrastructure, a sympathetic legal environment, and educational and training

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[8] In economics, a public good is a good that is both non-excludable and non-rivalrous in that individuals cannot be effectively excluded from use and where use by one individual does not reduce availability to others.

systems are conducive to innovation activities. The Scottish Government's actions on these issues are discussed in the introduction chapter. In addition to R&D support governments can also provide fiscal incentives. Fiscal incentives are seen as horizontal in their impact as they are available to all private firms. Public R&D funding is seen as vertical as it is selective and targets specific projects or firms either for their own needs (carbon reduction) or to support industry (knowledge creation).

3.2.3 Investment Support

Countries can support renewable technologies through fiscal policies such as investment tax credits, rebates on general energy taxes, and rebates on emissions taxes, lower VAT rates, special tax status for green investment funds, exemption or reduction of business rates and capital asset taxes, and others.

Scotland initiated in 2012 a £103 million Renewable Energy Investment Fund (REIF) that will initially focus on supporting communities and rural businesses to develop their own local renewable projects, on supporting district heating, and on supporting wave and tidal developers with the development and deployment of array projects.

3.2.4 Open markets

Electricity markets have been heavily regulated for most of their history and have been characterised by restricted entry and exit. However, during the past 20-30 years many power markets in developed nations have reduced the amount of state control and allow greater participation, especially of generation firms. Open markets are more common today with independent power producers being allowed to enter the market and sell electricity to wholesale distribution companies. Although all participants in the electricity market are still regulated to some degree, many governments have developed a 'light touch' approach. Although there are many different market structures being used today in many countries two basic forms of open markets are common. The first is a pool structure where all power producers present an offer price for delivery of specified power outputs to a central clearing house who also receives purchase offer prices from power distribution firms. From this information a market clearing price is established and trade is conducted with neither the producer/seller nor purchaser/consumer being in direct contact but only dealing with the central clearing house. The second market structure is bilateral contract where producers and consumers negotiate specific contracts and trade with each other. In this case a central authority is active to ensure that the electric grid is operated to assure grid security and balance in the event of an excess or shortage of power.

Open markets have allowed for limited success in deploying renewable energy generation. The generally higher cost of renewables, with the exception of hydroelectric, has been a detriment to entry as the technologies are rarely price competitive. The few instances of success without intervening government policies are voluntary green energy purchase programmes when consumer could pay a premium for their retail distribution company to provide low-carbon electricity directly to them or purchase offsetting low carbon energy elsewhere.

3.2.5 Green certificates

Green certificates are tradable commodities that represent the environmental quality of electricity that has been generated by low carbon emissions technology. Green certificates are also known as Renewable Energy Certificates (RECs), Green Tags, Renewable Energy Credits, Renewable Electricity Certificates, Tradable Green Certificates (TGCs) and Tradable Renewable Certificates (TRCs). In the UK they are known as Renewable Obligation Certificates (ROCs). Common practice is for the renewable electricity generating company to be issued one certificate for each one MW of electricity supplied. The objective of the programme is for the generating company to have two saleable commodities that provide an enhanced revenue stream – electricity and certificates, thus incentivising earlier deployment of renewables. These certificates can be sold and traded or bartered, and the owner of the green certificate can claim to have purchased renewable energy.

The two main markets for green certificates are compliance markets and voluntary markets. The compliance market is often called a Renewable Portfolio Standard and is discussed below.

Voluntary markets are ones in which customers choose to buy renewable power out of a desire to use renewable energy. Business firms can buy green certificates as a way of demonstrating their commitment to positive environmental business practices, while households participate in green energy programmes provided by retail electricity providers from personal preference.

One criticism of green certificate schemes is that they do not directly correlate to a reduction of higher carbon emissions electricity as it is difficult to identify which if any fossil fuelled technology was displaced in some power networks.

3.2.6 Portfolio standards

A Renewable Portfolio Standard (RPS) is a quota system that requires the market to produce, sell, or distribute a certain amount of energy from eligible renewable sources. The obligation is typically imposed by government regulation on consumption at some level in the electricity supply chain, most often on retail distribution companies based on their total sales of electricity. The portfolio standard can also be applied on production when a certain portion of a company's generation assets or electricity production must be low carbon based.

RPS programmes commonly co-exist and function with green certificate programmes. This is to simplify the trading of the physical commodity of green electricity. Companies are allowed to purchase green certificates as a form of compliance demonstrating the production and use of low carbon electricity without the actual transmission and delivery of the power to the company. This green certificate/RPS mixture is the essence of the UK's Renewable Obligation programme.

3.2.7 Feed-in-tariffs

Feed-in-tariffs (FIT) are a government programme where a minimum guaranteed price is paid to a producer of renewable electricity. (Couture, et al, 2011) Generally the price is at a higher level than the open competitive market value of less costly conventional generation technologies. This higher level is set in order to incentivise deployment of renewables at a faster rate than would otherwise occur. FIT policies typically contain four key elements:

- guaranteed access to the electricity network;
- secure long-term purchase agreements normally 15-20 years in duration;
- price levels based on the costs of producing renewable energy including a sufficient rate of return on the investment; and
- allowing participation by anyone with the ability to invest, including homeowners, business owners, federal, state, and local government agencies, private investors, utilities and not-for-profit organizations.

A UK-wide FIT was established in 2010. The programme was designed for small and moderate scale renewable electricity producers who could not effectively participate in the Renewable Obligation scheme.

3.3 Energy Market Reform (DECC-EMR, 2012)

As an example of electricity market reform (EMR) which impacts on the portfolio of generation, we now discuss the recent reforms introduced in the UK. The objective of the proposed energy market reform is to provide clear regulatory guidance and increased certainty for commercial firms and investors in the British electricity market. The ambition of the reform is to:

- deliver security of supply and;
- meet climate change goals;
- all at an affordable price to electricity consumers.

The reform will provide measures for transition from and eventual replacement of the current Renewables Obligation programme, among other issues.

The key motivator for the reforms is a major change of the generation mix currently underway in the UK, with one-fifth of the existing generation assets closing over the next decade and a large expansion of intermittent and flexible generation projects using either wind or natural gas occurring concurrently. Investment in generation and transmission assets will require up to

£110 billion by 2020; which is more than double the recent historic rate of investment. Providing market conditions to deliver this investment level has to be balanced against limiting the impact on prices on industrial, commercial and domestic consumers.

The main components of the EMR are:

Feed-in-Tariffs with Contracts for Difference (CfDs) - long-term commercial agreements designed to provide stable and predictable revenues and incentives for companies that invest in low-carbon generation. The CfD for intermittent generation is a two-way payment contract in which the renewables firm receives a top-up payment from the system operator to assure the firm receives payments equal to an established "strike price" if the market price for electricity is below the strike price; payments also occur in the opposite direction when the renewables firm must pay to the system operator any revenue received that exceeds the strike price. . The UK Government believes this arrangement will deliver a balance between long-term revenue certainty for the generator, while ensuring that consumers are not overcompensating developers;

Final Investment Decision (FID) – long-term commercial agreements between the Government and renewable generation firms will be authorized during the transition period between the Renewable Obligation and CfDs, thus enabling some of investments to come forward in advance of the CfD regime coming into force;

Capacity Market – a market to provide security of electricity supply will be created to ensuring sufficient reliable capacity is available. The market will consist of a competitive auction that will pay generators a guaranteed income to be available to meet peak demand. It will operate on a 4-5 year deployment schedule to allow for design and construction;

Renewables Transitional Measures - will be designed to ensure that existing investments operating under the Renewables Obligation will be assured of a predictable and sufficient ROC price until the RO programme ends in 2037. Entrance into the RO programme terminates in 2017. ; and a

Emissions Performance Standard (EPS) - will be implemented to moderate and limit the most polluting fossil fuel power stations.

3.4 Markets Structure and Incentives in Scotland and the UK

3.4.1 Markets prior to 2002

The Non Fossil Fuel Obligation in England & Wales (NFFO)/ Scottish Renewable Obligation (**SRO**)

The Non Fossil Fuel Obligation (NFFO) and the Scottish Renewables Obligation (SRO) were introduced by the Electricity Act 1989. Before the introduction of the Renewables Obligation in 2002, they were the UK and Scottish Government's primary instrument of renewable energy policy. The SRO was the Scottish Government's parallel programme to England & Wales' NFFO. (OFGEM, 2012)

The NFFO originally required Public Electricity Suppliers (PES) in England and Wales to purchase electricity from renewable generators and provided for purchases to be at fixed prices with long term contracts. Typical contracts had duration of 15 years. The PESs established the Non Fossil Purchasing Agency Limited (NFPA) in England and Wales to enable them to carry out their obligations to collectively contract with renewable generators and so comply with the programmes. The Scottish Supply Successor Companies (SSE Energy and Scottish Power) were the purchasers of SRO power until March 2006 when the Non Fossil Purchasing Agency Scotland Limited (NFPAS) became the purchaser. The NFFO and SRO schemes are no longer open to new generators, but existing contracts will continue until the last of them expires in 2019.

When the programme started in 1990 the major beneficiaries were nuclear power generators which were owned by the UK Government, who enjoyed higher revenues as a result of the scheme. Renewable energy projects also qualified as non-fossil fuelled generators. Power purchase agreements were negotiated with each existing qualifying generator at the start of the programme. New renewable projects were contracted by competitive bidding. This resulted in many projects not being built, as the bid price was later found to be unrealistically low.

The electric power was sold by the NFPA in open auctions to distribution companies in England and Wales. In Scotland the major power companies, SSE Energy and Scottish Power, purchased all the electricity for their retail operations.

Funding to support the NFFO/SRO was provided by the Fossil Fuel Levy, a levy placed on all fossil fuelled electricity consumed in the UK, thus providing a price advantage to both nuclear and renewables. The fund was meant to cover any short fall between purchase price and the public auction price with excess funds to be used to promote renewable energy development. The levy reached heights of 1.2% in Scotland (10.6% in England and Wales) but has been set at zero per cent since 2002.

All NFFO/SRO projects became eligible for Renewable Obligation Certificates (ROC) in 2002 and belong to the respective funding agency. ROCs are described in detail in Section 3.2. In England and Wales the electricity and all associated credits /certificates are auctioned together. See Table 3.2 for recent auction values. Municipal waste incineration (MWI), with or without CHP, is not eligible for ROCs, only LECs and REGOs. Levy Exemption Certificates (LECs) are evidence of Climate Change Levy(CCL)- exempt electricity supply generated from qualifying renewable sources, thus have value by avoiding payment of the CCL. REGO is a certificate issued by Ofgem to certify that the electricity in respect of which it was issued was produced from eligible renewable energy sources. The primary use of REGOs in Great Britain and Northern Ireland is for Fuel Mix Disclosure (FMD). FMD requires licensed electricity suppliers to disclose to their customers, and potential customers, the mix of fuels (coal, gas, nuclear, renewable and other) used to generate the electricity supplied annually. The price differential between MWI and wind, qualifying-hydro and landfill gas reflects the value of ROCs for which the later qualify. The differing auction prices imply a ROC value of £45 - £47 which is comparable to the ROC only auction prices found in Scotland. See Table 3.3.

Table 3.4 Average Auction Prices for electricity – NFFO (January 2012)

Summer 2012[1]	
Technology Band	**Average price (£/MWh)**
Municipal Waste Incineration	£45.40
Municipal Waste Incineration CHP	£52.80
Wind	£89.50
Hydro	£89.60
Landfill Gas	£92.20

[1] At present, on-line auctions are held biannually. These auctions are for electrical output which will be produced by generators during a six month period (starting 1st April or 1 October) following the end of the auction. These auction prices are for electrical output together with, depending on the generation technology, ROCs LECs and REGOs.

Source: Non-fossil Fuel Purchasing Agency (2012) ROCs are auctioned off separately in Scotland from electric power and are a major source of renewables development funding for the respective governments. All moneys received are deposited in the respective Fossil Fuel Levy accounts. In 2011 the UK and Scottish Governments came to an agreement that will allow the Scottish Government to access and spend half of the Scottish Fossil Fuel Levy fund, which held around £200 million. (HM Treasury, 2011) The remaining £100 million is being used as partial capitalisation of a UK-wide Green Investment Bank.

3.4.2 Markets since 2002

England &Wales Renewables Obligation (RO) and Renewables Obligation Scotland (ROS)

The Renewables Obligation is currently the main support scheme for renewable electricity projects in the UK. The Renewables Obligation (RO), the Renewables Obligation Scotland (ROS) and the Northern Ireland Renewables Obligation (NIRO) are designed to incentivise renewable generation in the electricity generation market. They place an obligation on UK suppliers of electricity to source an increasing proportion of their electricity from renewable sources. (DECC, 2012)

The RO places a mandatory requirement on licensed UK electricity suppliers to source a specified and annually-increasing proportion of electricity they supply to customers from eligible renewable sources or pay a penalty. See Table 3.4 for annual requirement levels to date.

Table 3.5 Annual ROC Obligation level and buy-out penalty, 2002 -2013

Obligation period	Portion of total electricity supplied to be met by ROCs	Buy-out penalty price
1 April 2002 to 31 March 2003	3%	£30.00
1 April 2003 to 31 March 2004	4.30%	£30.51
1 April 2004 to 31 March 2005	4.90%	£31.39
1 April 2005 to 31 March 2006	5.50%	£32.33
1 April 2006 to 31 March 2007	6.70%	£33.24
1 April 2007 to 31 March 2008	7.90%	£34.30
1 April 2008 to 31 March 2009	9.10%	£35.76
1 April 2009 to 31 March 2010	9.70%	£37.19
1 April 2010 to 31 March 2011	11.10%	£36.99
1 April 2011 to 31 March 2012	12.40%	£38.69
1 April 2012 to 31 March 2013	15.80%	£40.71

Source: Author, OFGEM Renewables Obligation Annual Reports, 2003-2012

The scheme is administered by OFGEM who issue Renewables Obligation Certificates (ROCs) to renewable electricity generators for every MWh of eligible renewable electricity they generate. Initially one ROC was issued for each eligible MWh; in 2009/10 a banding scheme was instituted, whereby OFGEM awarded different numbers of credits per MWh according to type of renewable technology. Generating companies sell their ROCs to suppliers or traders, which thus allows them to receive a second revenue stream in addition to the revenue from the wholesale electricity price. (DECC, 2012a) The market for ROCs is generally non-public and confidential. It is conducted through bilateral negation between renewable energy companies that sell ROCs and suppliers that must purchase ROCs to meet the obligation, or through market makers. However, there is one open public auction for ROCs held by the NFPAS. Table 3.3 lists historic auction prices and reflects the value electricity supplies are willing to pay for them. The average annual value has fluctuated between a low of £41.13 to a high of $51.49. Since 2007 various modifications have been instituted in the RO programme to assure that ROC prices are maintained in a range near £50.

Table 3.6 Average Annual Auction Price for ROCs, 2002-2012

Auction Date[1]	Average ROC Price
2011	£49.32
2010	£47.65
2009	£50.72
2008	£51.49
2007	£47.77
2006	£41.13
2005	£44.53
2004	£48.69
2003	£47.09
2002	£47.12

[1] Average auction price. Multiple auctions were held in 2003-2012.
Source: Author, NDPAS data. Available at: http://www.e-roc.co.uk/trackrecord.htm

Suppliers present ROCs to OFGEM to demonstrate their compliance with the obligation. Since 2009 a change in the RO requires that a 10% 'headroom' exist between the forecasted amount of renewable energy produced and the amount of the required ROCs. This is to ensure significant buy-out funds are paid to Ofgem.

If the supplier does not submit adequate ROCs, the supplier has to pay a penalty known as the buy-out price. This is set at £40.71 per ROC for 2012/13. The penalty value is linked to the UK retail price index and set on annual basis, Table 3.7 below.

Table 3.7 Annual Buy-out Price per ROC, 2002-2013

Obligation period 1 April - 31 March	Buy-out price
2002-2003	£30.00
2003-2004	£30.51
2004-2005	£31.39
2005-2006	£32.33
2006-2007	£33.24
2007-2008	£34.30
2008-2009	£35.76
2009-2010	£37.19
2010-2011	£36.99
2011-2012	£38.69
2012-2013	£40.71

Source: OFGEM (2012b) Information Note – 9 February 2012.

The money collected by OFGEM is deposited into a buy-out fund which is recycled on a pro-rata basis to suppliers who presented ROCs. Suppliers that do not present ROCs pay into the buy-out fund at the buy-out price, but do not receive any portion of the recycled fund. The proceeds of the buy-out fund are paid back to suppliers in proportion to how many ROCs they have presented. By submitting ROCs to OFGEM, suppliers avoid having to pay the buy-out penalty and receive a proportion of the buy-out fund back, thus making the market value of ROCs greater than the penalty price. This increases the revenue received by the eligible renewable energy companies.

Costs

According to OFGEM, the value of the RO scheme for the 2011-12 compliance is estimated to be £1.487 billion. This value represents the estimated 310 TWh of electricity supplied in the UK during that period multiplied by the 12.4% obligation level to be met by ROCs, then multiplied again by the 2011-12 ROC buy-out price of £38.69. Unfortunately, these UK wide costs cannot be disaggregated to the sub-UK government level. By the same method the 2010-11 compliance period had a value of £1.285 billion.

Costs to government

OFGEM and Northern Ireland Authority for Utility Regulation (NIAUR) recover the cost to administer the RO from the buy-out fund. In September 2011 the total recovered was £3.6 million, which represents 0.22% of the total value of the scheme for 2011-12. This is a small percentage increase from the 2010-11 costs of £2.3 million (0.18% of the value for that year) and mainly reflects the additional work needed following the introduction of sustainability criteria requirements to the RO in 2011.

Costs to consumers

For the compliance period of 2010-11 the average household experienced an increased annual electricity bill of £15.15 as a result of the Renewables Obligation. With 26.3 million households accounting for 31% of electricity consumption the domestic sector accounts for a gross RO cost of £398.5 million. (DUKES, 2011) Offshore and onshore wind accounted for 51.1 per cent of ROCs in 2010-11 (20.2 per cent and 30.9 per cent respectively), giving a cost per household for wind of £7.74; onshore - £4.68 and offshore - £3.06. These values equate to 1.8% (1.1% - onshore and 0.7% - offshore) of median household electric bill in 2010. OFGEM reported the 2010 medium household electricity bill was £424, based on a standard direct debit account. (OFGEM, 2012c) The bill is based on an annual consumption figure of 3,300 kWh for electricity, averaged across the six major retail energy suppliers and across Great Britain.

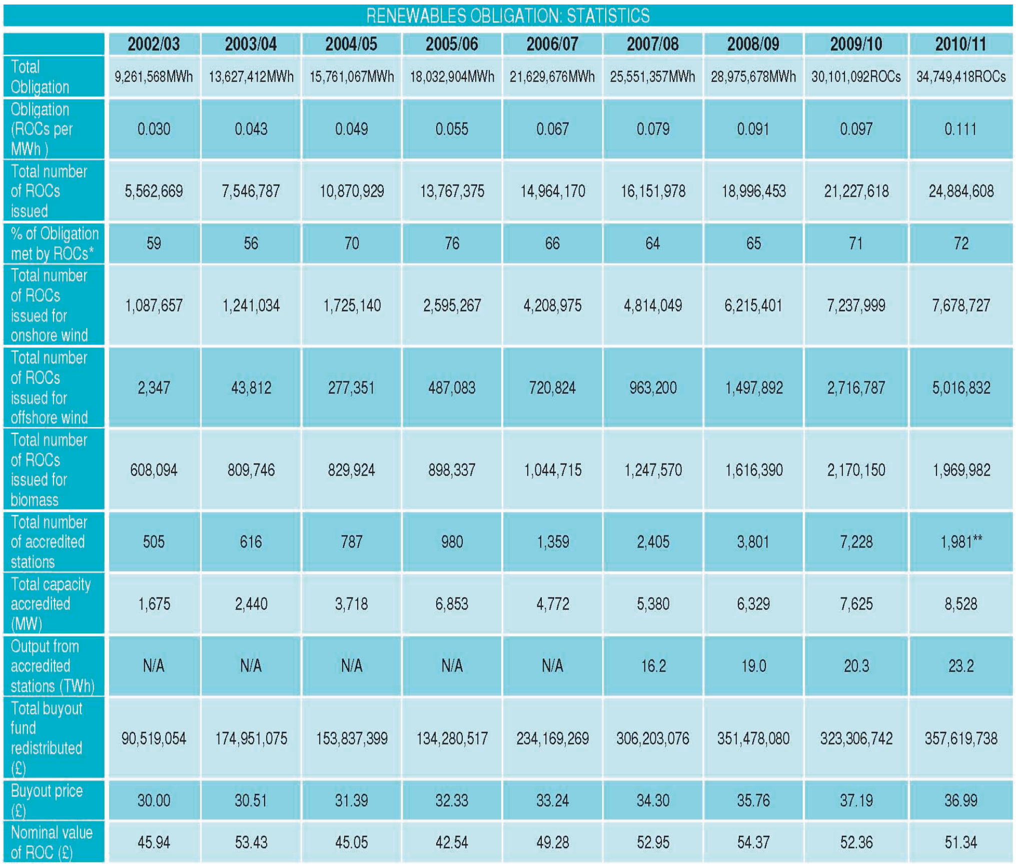
Costs to industry

Industry and commercial businesses accounted for 47% of the electricity consumed in the UK in 2010, 27% and 20% respectively. (DUKES, 2011) This indicates that as a result of the RO programme the UK industrial sector incurred an additional £347 million in electricity costs, while the UK commercial sector incurred £257 million. The total cost coming to $604 million.
Other sectors incurred the following RO costs:

- Fuel Industries (7% of consumption) - £90 million.
- Public Administration (5% of consumption) - £64 million.
- Transport (1% of consumption) - £13 million.
- Agriculture (1% of consumption) - £13 million.

The following table, Table 3.8, presents a full statistical overview of the Renewable Obligation since inception in 2002/3 through the end of the 2010/11 operating year. Total ROC's issued increased to slightly less than 25 million certificates since 2002, representing 24.9 GWh of electricity generated by eligible renewables generators. Eligible renewables generation capacity grew from 1,675MW to 8,528MW. The redistributed buy-out fund was £357.6million which created a nominal ROC value of £51.34 in the 2010/11 period, as compared to a buy-out price of £36.99.

Table 3.8 Renewables Obligation Statistics, 2002/03 – 2010/11



RENEWABLES OBLIGATION: STATISTICS

	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11
Total Obligation	9,261,568MWh	13,627,412MWh	15,761,067MWh	18,032,904MWh	21,629,676MWh	25,551,357MWh	28,975,678MWh	30,101,092ROCs	34,749,418ROCs
Obligation (ROCs per MWh)	0.030	0.043	0.049	0.055	0.067	0.079	0.091	0.097	0.111
Total number of ROCs issued	5,562,669	7,546,787	10,870,929	13,767,375	14,964,170	16,151,978	18,996,453	21,227,618	24,884,608
% of Obligation met by ROCs*	59	56	70	76	66	64	65	71	72
Total number of ROCs issued for onshore wind	1,087,657	1,241,034	1,725,140	2,595,267	4,208,975	4,814,049	6,215,401	7,237,999	7,678,727
Total number of ROCs issued for offshore wind	2,347	43,812	277,351	487,083	720,824	963,200	1,497,892	2,716,787	5,016,832
Total number of ROCs issued for biomass	608,094	809,746	829,924	898,337	1,044,715	1,247,570	1,616,390	2,170,150	1,969,982
Total number of accredited stations	505	616	787	980	1,359	2,405	3,801	7,228	1,981**
Total capacity accredited (MW)	1,675	2,440	3,718	6,853	4,772	5,380	6,329	7,625	8,528
Output from accredited stations (TWh)	N/A	N/A	N/A	N/A	N/A	16.2	19.0	20.3	23.2
Total buyout fund redistributed (£)	90,519,054	174,951,075	153,837,399	134,280,517	234,169,269	306,203,076	351,478,080	323,306,742	357,619,738
Buyout price (£)	30.00	30.51	31.39	32.33	33.24	34.30	35.76	37.19	36.99
Nominal value of ROC (£)	45.94	53.43	45.05	42.54	49.28	52.95	54.37	52.36	51.34

*For England and Wales only. ** The decrease of stations from 09/10 is due to the migration of most micro-generating stations to the FIT scheme.

Source: DECC (2011b) Renewables Obligations Statistics.

Recent market changes

ROC Banding

All eligible technologies were treated equally under the Renewables Obligation when it first started in 2002 with all receiving one ROC for each MWh of electricity generated. After a several years of operation two interrelated problems with this approach were identified. The first being that new private investment in renewable energy projects was being concentrated on the lowest cost commercially deployable technologies, i.e. onshore wind farms.

This raised concerns over the diversity of supply, and increasing public opposition to new on-shore wind farms. The second interrelated problem was that other technologies were not experiencing the same supply push, meaning R&D and pilot demonstration projects in other renewable technologies were receiving inadequate private funds.

This was particularly relevant to Scotland and its marine renewable resources that could be developed through the use of wave, tidal and tidal stream energy technologies. The Scottish Government is committed to supporting the development of wave and tidal energy capacity in Scottish waters, and positioning Scotland as a world leader in the development of these technologies. Scotland boasts 25% of Europe's tidal resource and 10% of its wave resource. To give it greater support the Scottish Government to introduce higher levels of support for wave and tidal stream generation under the ROS and introduced a Marine Supply Obligation in 2007. This has since been superseded by the introduction of enhanced ROC bands for wave and tidal stream in April 2009.

England and Wales followed Scotland in developing and harmonizing banding of ROCs to different technologies based on their current cost of producing energy and the level of incentive necessary to attract R&D funds. The following table presents the banding proposed for the most recent RO period. The ratio of ROCs/MWh is indexed from a baseline of one ROC/MWH for onshore wind and ranges from two for some types of biomass and marine technologies to 0.25 for landfill gas which is currently cost competitive with conventional power sources even without the ROC support.

Table 3.9 ROCs issued by technology band, 2011-12

Generation Technology	ROCs/MWh
Hydro-electric	1
Onshore Wind	1
Offshore Wind	1.5
Wave	2
Tidal Stream	2
Tidal Impoundment – Tidal Barrage	2
Tidal Impoundment - Tidal Lagoon	2
Solar Photovoltaic	2
Geothermal	2
Geopressure	1
Landfill Gas	0.25
Sewage Gas	0.5
Energy from Waste with CHP	1
Gasification / Pyrolysis	2
Anaerobic Digestion	2
Co-firing of Biomass	0.5
Co-firing of Energy Crops	1
Co-firing of Biomass with CHP	1
Co-firing of Energy Crop with CHP	1.5
Dedicated Biomass	1.5
Dedicated Energy Crops	2
Dedicated Biomass with CHP	2
Dedicated Energy Crops with CHP	2

Source: DECC (2012e) Table 6.3 Renewables Obligation: certificates and generation.

The Scottish Government and UK Government are proposing marine technologies receive increased support to five ROC/MWh in future years. Subsidy levels in the UK are due to drop for onshore and offshore wind, following provisional updated ROC bandings, though the drops were lower than many had feared. Onshore wind is due to receive 0.9 ROCs from 2014, compared with the present 1 ROC, and offshore wind is due to receive 1.9 ROCs for 2015-16, and 1.8 ROCs from 2016-17 onward, down from the 2 ROCs it currently receives. (Ernst & Young, 2011)

Both Scottish and UK governments have given commitments to the principle of grandfathering – the position of those who have made significant investments should be protected in terms of the number of ROCs they receive. Only generating capacity which becomes operational on or after 1 April 2009 will receive the new ROC banding that has been put in place.

Feed-in-tariff

The Feed-in Tariffs (FITs) scheme was introduced in April 2010, under the Energy Act 2008. (DECC, 2012b) The FIT scheme is intended to encourage the uptake of small scale renewable and low-carbon technologies up to a total installed capacity of 5MW in England, Wales and Scotland. The FIT scheme creates an obligation for certain Licensed Electricity Suppliers to make tariff payments for the generation and export of renewable and low carbon electricity. Installations using solar photovoltaic, wind, hydro, anaerobic digestion technologies up to 5MW and fossil fuel derived Combined Heat and Power up to 2kW can receive FIT payments, providing all eligibility requirements are met.

This scheme replaces the Renewables Obligation (RO) as the main mechanism of support for micro-scale PV, wind and hydro installations with a declared net capacity of 50kW or less. The scheme also provides small-scale generators with a capacity over 50kW up to 5MW the one-off choice of operating under the FIT or the RO.

The operational procedures for the FITs programme consist of six steps (OFGEM, 2011):

1. Customers install eligible renewable generator technology using a Microgeneration Certification Scheme installer or request accreditation via OFGEM for specified technologies and small-scale systems.
2. Customer registers with supplier for FITs. Supplier adds generator to Central Register overseen by OFGEM.
3. Customer provides quarterly meter readings to Supplier.
4. Supplier makes payments to customer.
5. OFGEM spreads costs across all UK suppliers via levelisation procedures.
6. OFGEM monitors supplier compliance.

All licensed electricity suppliers (regardless of FIT participation status) are required to make payments into Ofgem E-Serve’s levelisation fund, based on their market share of the Great Britain electricity supply market and any FIT payments made to accredited installations under the FIT scheme. The fund is then redistributed to FIT licensees that have made more payments to accredited installations than they would be required to by their market share contribution. Currently this process occurs on a quarterly basis.

Tariff payments vary depending on the technology and the size of project. The following table illustrates established tariffs in 2011. Once registered for FITs, the generation tariff received will last for the tariff lifetime and will be adjusted annually for inflation based on the Retail Price Index. A total of £35,937,000 in FIT payments was due to generators for electricity produced between October 2011 to 31 December 2011.

The cumulative number of installed renewable energy systems registered under the FIT programme reached slightly less than 150,000 by the end of 2011. See Table 3.11. The rate of public participation significantly accelerated during the last six months of 2011 with over 100,000 systems being installed.

Table 3.10 FIT installations by quarter, April 2010 to December 2011

	April-June 2010	July-September 2010	October-December 2010	January-March 2011	April-June 2011	July-September 2011	October-December 2011	Total
Hydro	4	108	48	44	14	18	18	254
Photovoltaic	2,698	7,813	6,663	11,378	14,532	35,436	65,930	144,450
Wind	60	632	330	316	185	321	235	2,079
MicroCHP	0	5	17	78	58	96	61	315
Anaerobic digestion	0	0	2	1	2	5	4	14
Total	**2,762**	**8,558**	**7,060**	**11,817**	**14,791**	**35,876**	**66,248**	**147,112**

Source: OFGEM, Feed-in-Tariff Update, Issue 7, March 2012 Available at: http://www.ofgem.gov.uk/Sustainability/Environment/fits/Newsletter/Documents1/Feed-in%20Tariff%20(FIT)%20Update%20Newsletter%20Issue%207.pdf

661.07MW of Total Installed Capacity has been registered under the FITs scheme since 1 April 2010. Solar photovoltaic has been the dominant technology taken up as a result with a 90% share. See the following table for further details. The level of PV investment resulted from higher than forecast rates of return being earned by households, greater than 10%, as a consequence of lower than predicted capital and installation costs; PV panels experience up to a 40% retail price decrease and industry expansion created competitive pricing by PV installers. The pace of growth was much faster than the Government anticipated. The Government had constructed the FIT to provide a 5%- 8% rate of return. DECC had forecast total registered solar PV capacity would reach 94MW in September 2011 and 137MW by April 2012. The 94MW target was reached four months ahead of schedule in May 2011, and by November 2011 the April 2012 target was exceeded by more than two and a half times. (HoCL, 2012)The current total solar PV capacity is approximately 4% of renewables capacity and 0.4% of total generating capacity in the UK. If the Government took no action, by 2014-15 FITs for solar PV would be costing consumers £980 million a year, adding around £26 (2010 prices) (6% of median household electric bill) to annual domestic electricity bills in 2020. (HoCL, 2012)

Chris Huhne, Secretary of State for Energy and Climate Change order a review of the PV incentive in December 2011. He stated, "In light of the economic and fiscal situation, inherited by the Coalition, it is imperative that we take a more responsible and efficient approach to public subsidy, including where this subsidy is funded through energy bills."

Table 3.11 FIT installed capacity, April 2010 to December 2011

Technology	Percentage of Capacity
Hydro	3%
Anaerobic digestion	2%
Wind	5%
Micro CHP	<1%
Photovoltaic	90%

Source: OFGEM, Feed-in-Tariff Update, Issue 7, March 2012 Available at: http://www.ofgem.gov.uk/Sustainability/Environment/fits/Newsletter/Documents1/Feed-in%20Tariff%20(FIT)%20Update%20Newsletter%20Issue%207.pdf

Indirect Markets and Costs

Security of Supply

There are three issues that will dominate Scotland's energy future for the next 40-50 years. These are typical for any country thinking about its energy futures. The issues are:

- security of supply,
- meeting renewable and emission reduction targets, and
- costs of energy to consumers. (RSE, 2012)

Security of energy supply in Scotland is a pressing issue that is growing with the passage of time as large conventional power stations are due to close this decade. World leading commitments have been given by the Scottish Government for transitioning to a low-carbon economy. At the same, there is a need to avoid significant energy cost increases from this changing energy mix, while in the short run trying to invigorate an economy that is currently experiencing very slow growth. A Royal Society of Edinburgh reports illustrates this balancing of issues with a nice example. A gas-burning plant required to ensure security of supply could be built quickly, but without contributing much to emission reduction targets; or large arrays of wind power could be built which contribute more to emission reduction targets, but at unacceptably high costs.

As Scotland expands its renewables capacity, its energy infrastructure will look substantially different than its current profile. Most significantly it will require reconfiguring the transmission network to allowing for widely distributed on-shore and off-shore developments to be connected to the grid competitively.

Other extensive changes and improvements will need to be made in order to create a resilient, stable electrical system. Scotland will need large scale electricity storage capacity; a number of transmission interconnectors that will allow electricity to be imported and exported internationally (for example, from Iceland, or to England); and a system that is stable despite a large portion of intermittent renewable power generation sources.

Costs to electricity infrastructure

The UK has an aging electric grid and a large portion of generating assets that are due for decommissioning this decade. Some of this decommissioning is the result of regulatory limits on highly polluting power plants while others are end-of-life facilities. Up to £110 billion investment in electricity generation and transmission is likely to be required by 2020, more than double the current rate of investment. £35 billion of transmission expansion or upgrade are required in the UK and £75 billion of generation expansion or replacement in needed.

The two major power companies in Scotland, Scottish & Southern Energy and Scottish Power, want to spend £4 billion in new transmission connections in the northern part of Scotland and £3 billion in the southern or central parts of Scotland, respectively. Since no new nuclear power stations or coal-fired power stations are permitted at this time are to be built in Scotland, most of this will be to connect new wind-farm developments. A key reason for the development plans are the connection of offshore and onshore wind generation in Scotland estimated to be 11GW within 10-20 years. The proposals would also increase the export capacity from Scotland to England from 3.3GW to close to 7GW by 2021.

The proposal to build a high voltage power line from the north to the central population area of Scotland, the Beauly-Denny line, highlights the fact that there are external costs that will also be incurred. The transmission line will transit 137-miles using a network of 600 pylons, some more than 200ft in height. There were 18,000 objections to the project lodged during the planning process as it was proposed, but the Scottish Government ruled construction of the line was essential to connect a large quantity of renewable energy projects proposed for the Highlands and Islands. (BBC, 2010 & 2012)

Map 3 Beauly – Denny Transmission line

Source: BBC (2010)

Intermittency and generation reserve requirements

There are two main categories of cost associated with intermittency: system balancing costs and back up generation costs.

System balancing costs (CCC,2008; Försund and Hjalmarsson,2011)

System balancing costs relate to the short term (i.e. minutes to hours) adjustments which are needed to manage the balance between supply and demand at each instant in time. The network system operator is responsible for making these adjustments.

The costs of system balancing are made up of the costs of building and running fast response reserve generation plants. There are also costs associated with changes in the use of other power plants on the system, for example, efficiency losses due to increased variation in the output of a thermal plant, and wasted energy if intermittent output exceeds the ability of the system to use it.

Back up costs

Back-up costs are the long term costs associated with ensuring that sufficient installed generation capacity will be available at times of peak demand when renewable supply levels are low due to weather conditions. Costs are incurred when conventional plant is retained on the system or constructed to provide the necessary back-up capacity to ensure that peak demand is met. Back-up costs are thus made up of the capital and fixed operating and maintenance costs of adding to the reserve capacity.

Back-up costs arise from the fact that the contribution of an intermittent generator to reliability is lower than a conventional generator that can deliver on average the same amount of energy, as the variability in output of intermittent generators means they are less likely to be generating at full power at times of peak demand. The total incremental cost of providing capacity reserves and balancing, of which roughly two-thirds is for the reserves and one-third for balancing, is in the range 0.65-0.75 p/kWh (2006 £ value). These estimates imply that each MW of thermal plant capacity replaced by a wind plant would require approximately 3 MW wind capacity plus 0.6-0.7 MW (2006 £ value) of reserves in the form of OCGTs or delayed retirements of thermal plant.

4 Beneficial Economic Impacts of Renewables

4.1 Introduction

The benefits that can be derived from renewable energy are wide and varied, ranging from less air pollution to local employment. A large portion of the benefits, if not the significant majority, are not private benefits but rather public benefits. It is partly for this reason that renewable energy sources and technologies are being promoted by governments around the world. Some of the benefits are difficult to capture by any one individual or group but are inherently shared by others. The avoidance of carbon pollution, thereby mitigating global climate change, by the use of renewable energy technology benefits all people on the planet. It is not possible to exclude anyone from this benefit and there is no rivalry, if one person enjoys the benefit it does not diminish the benefit for others. This chapter will discuss economic benefits that range in scale from national impacts to regional and local community that gain from deployment of renewable energy projects in general and onshore wind in particular.

The chapter starts by discussing the most important of private benefits, financial profit from investing in renewable energy. It is followed by projections on potential new job creation and increased national and regional economic growth. Both direct and indirect jobs and economic growth is examined. The final benefits discussed are the potential increase in government revenue collection from corporate taxes as well as from increased business rates. Rural and community development from locally owned RE projects are the last benefits to be discussed' it is followed by conclusions on the overall benefits of RE projects. In the next chapter, we discuss the valuation of public good benefits (and costs).

4.2 Benefits to RE industry

4.2.1 Profits

The overarching objective of the various UK and Scottish Government programmes to promote renewable electricity production was to create a framework where private firms or individuals would earn sufficient profits to motivate an inflow of investment capital. If profits are higher than normal for the level of business risk entailed there is the expectation that industry would expand faster. The expansion of renewable electricity production from 5.56 million MWh in 2002/03 to 24.88 million MWh in 2010/11 (a 440% increase in 9 years) under the RO scheme demonstrates that higher than normal profits where created in the renewable energy industry and the desired expansion occurred. It is important to remember that high profits were the tool to incentivise faster deployment of renewables. These incentives were partly created by deliberate state intervention in the electricity market.

The RO has been successful in creating two revenue streams for a renewable energy firm; one stream from the sale of electricity and the other from the sale of ROCs. According to OFGEM, the value of the RO scheme for the 2011-12 compliance period is estimated to be £1.487 billion, while the 2010-11 compliance period had a value of £1.285 billion. These are additional earnings paid to suppliers of renewable electricity above the earnings received for selling electricity. However, In the UK electricity and ROC markets most transactions at the generation level are bilateral and confidential. This makes it difficult to have profit estimates for specific firms.

However, a rough estimation can be made of the above normal profit on a per MWh basis for wind farms recently constructed. Recalling that the calculated value for levelised cost of electricity generation includes the normal rate of return and profit it can be shown that the potential revenue for onshore and offshore wind is greater than the levelised cost and therefore supernormal profits are occurring.

Table 4.1 Levelised Cost of Electricity for Wind Farms (Projects started 2011)

Type of Wind Project	Levelised Costs (£/MWh)
Onshore 5MW>	£90.20
Onshore <5MW	£104.90
Offshore Round 2	£121.60
Offshore Round 3	£147.50

Source: DECC (2011a)

Assuming an average ROC value of £48.50 as determined by the Non-fossil Fuel Purchasing Agency Scotland (NFPAS) auctions during 2010/2011 and the current forecasted levelised cost of electricity for wind farm projects started in 2011 (see Table 3.1 above), it can be shown that above normal profits exist if the electricity generated is sold for more than £41.70 to £56.40 for onshore wind and £24.60 to £50.50 for offshore wind. Average wholesale electricity prices have been in the range £55.00 to £60.00 during Spring 2012. It must be noted that transmission costs have not been incorporated into this estimate.

Transmissions costs in the UK are allocated to both the electricity generator and the purchaser, normally a retail supplier or distribution company. Tariffs are determined based on zones; with charges being higher the farther north a generator is located from the dominant share of consumption, which occurs in the south of England. The zonal costing model requires Scottish generators, including renewables, pay a higher price than other power producers, which does have an impact on their profitability. The average cost of transmission across the entireUK is approximately £2.00 per MWh with costs in northern Scotland exceeding £21 per MWh and future transmission from the Shetland Islands possibly being £70 per MWh.

Table 4.2 **Minimum value of electricity necessary to exceed Levelised Cost of Electricity**

	Onshore 5MW>	Onshore <5MW	Offshore Round 2	Offshore Round 3
LCOE	£90.20	£104.90	£121.60	£147.50
Value of ROC	£48.50	£48.50	£97.00	£97.00
Minimum value of electricity necessary to exceed LCOE	£41.70	£56.40	£24.60	£50.50

Source: Authors

4.3 Industrial sector creation and expansion

There is a life cycle to each technology that needs to be considered when examining the creation and expansion of renewables as an industrial sector. Each stage has its own demands as far as the economic development that can occur. The four stages are: (1) Planning; (2) Construction; (3) Operation; and (4) Decommissioning or Repowering.

4.3.1 Planning and construction

Development and construction are the first of two stages in the life cycle of a wind farm. The development stage consists of project design, environmental studies, legal agreements, project funding and planning permissions. Construction consists of preparing the site, manufacturing and installing the wind turbines and connecting to the transmission network.

Construction of the balance of plant (non-turbine parts of a wind farm) provides the most significant opportunities for UK companies to participate in this stage. Manufacture of the turbines has to this date been conducted outside the UK with continental Europe being the dominate location of manufacture for UK installed turbines. However, many of the 8,000 components required to manufacture a turbine are produced in the UK and exported overseas. Several major turbine manufacturers are considering establishing facilities within the UK or have already done so.

4.3.2 Operation and maintenance

Operations and maintenance, the third life cycle stage, consists of maintaining and operating the site and the turbines for the project life which is typically anticipated to be 25 years. This phase consists of a relatively low level of economic activity when compare to the construction phase. Operation and maintenance of a wind farm involves a limited amount of highly skilled labour, while maintenance costs are estimated to be about average 2%-3% of the original construction cost per annum over the life of the project.

4.3.3 Decommissioning or Repowering

All renewable energy projects have a finite life span as the asset ages and it no longer economical to continue operations with increasing maintenance costs. Major hydroelectric dams may go 50 to 100 years or more before considering decommissioning, wind farms are unlikely to go more than 20-30 years. Each technology faces its own life cycle. Onshore wind has been around long enough to face the decommissioning question, but these older wind turbines are small relative to current installations, less than 1MW in size. The large multi-MW turbines have years until significant quantities face the decommissioning question. Costs are only estimated at this time.

Another alternative is to repower the wind farm. This means removing and replacing all components that are needed to have a fully functioning modern facility. There is a certain appeal to this and economic efficiency that may make this option attractive as the wind farm can continue operating while undergoing refurbishment given the modular nature of the turbines to the overall project.

4.4 Wider Economic Impacts from Wind Energy Deployment

A study by Biggar Economics (May 2012), commissioned by the UK Government, estimated that the total UK direct and supply chain impact of the onshore wind sector in 2011 was:

- 8,600 jobs and £548 million in Gross Value Added[9] across the UK;
- of the total UK impacts, 4,500 jobs and £314 million GVA arose at the regional/national level to individual wind farms (i.e. Scotland, Northern Ireland, Wales or English region); and
- of the regional/national impacts, 1,100 jobs and £84 million GVA arose at the local level for individual wind farms (i.e. local authority area).

The study found that 98% of development expenditure occurred within the UK, while the UK share of construction expenditures amounted to 45% and 90% of maintenance and operation expenditures.

For the offshore wind sector there were 3,100 full-time-equivalent employees working directly in UK offshore wind in 2010. (Renewables UK, 2011) When compared to onshore wind a smaller proportion of total workers are employed in planning and development activities. This is a direct result of the limited number of offshore sites, even though offshore projects are larger in scale and present greater difficulties in construction. The offshore construction challenge means an increased portion of employment is in construction, approximately 41% (961 FTE). Design and manufacturing account for only 7% (217 FTE) of jobs. Finally, around 16% (500 FTE) were employed in offshore wind operation and maintenance activities, representing about 17% (527 FTE) of total employment.

A wider scope report published by Scottish Renewables, a trade association organised for the renewable energy sector, reported in March 2012 that that the Scottish renewables industry as a whole is directly supporting at least 10,227 Full Time Equivalent (FTE) posts in project design, development, operation and its supply chain. Approximately 750 posts in renewable energy development and research exist in Tertiary Education institutions, while around 150 public sector employees are involved in renewables policy and management activities. It is stated the potential for employment growth is large as approximately six jobs in the supply chain exist for each job in the development category. A total employment of 11,136 FTE posts exists in Scotland currently.

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[9] Gross value added is used for measuring gross regional domestic product and other measures of the output of entities smaller than a whole economy.

Table 4.3 Total Employment in Renewable Energy in Development and Supply Chain

	Employees
Development	1,526
Supply Chain	8,701

Source: Scottish Renewables (2012).

Table 4.4 Total Employment in Renewable Energy Development and Supply Chain in Scotland by Technology

TECHNOLOGY EMPLOYEES	
Bioenergy	1,410
Grid	3,223
Solar and Heat Pumps	161
Hydro	503
Onshore Wind	2,235
Offshore Wind	943
Wave and Tidal	521
Working across Multiple Sectors	1,231
Higher and Further Education	757
Public Sector	152
TOTAL	**11,136**

Source: Scottish Renewables (2012).

Each job in the onshore wind energy sector or supply chain has a Gross Value Added impact of approximately £66,500 per annum.[10] Applying this estimate to alternative deployment scenarios[11] it is estimated that in 2020, the total direct and supply chain impact of the onshore wind sector in the UK according total GW installed could be (Biggar, 2012):

- 10GW would result in 8,700 jobs and and £580 million GVA;
- 13GW would result in 11,600 jobs and £780 million GVA;
- 15GW would result in 13,800 jobs and £913 million GVA 15GW; or
- 19GW would result in 17,900 jobs and £1,183 million GVA.

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[10] Calculated from data in Biggar (2012).

[11] Three of the scenarios (10GW, 13GW and 19GW) are the same as those adopted in the Renewable Energy Roadmap (DECC, 2012) and the other is from the National Renewable Energy Action Plan.

The induced effects, also called income (second round multiplier) effects, on the UK economy from spending by those directly employed or within the supply chain for onshore wind sector contributes approximately £85 million in GVA to the UK economy and supports approximately 2,400 jobs in businesses where employees spend their income.

By 2020, as with the preceding scenarios, could thus increase to:

- 10GW - £90 million and 2,500 jobs;
- 13GW - £122 million and 3,500 jobs;
- 15GW - £145 million and 4,100 jobs; or
- 19GW - £192 million and 5,400 jobs.

4.4.1 Impacts on other markets/industrial sectors

Expenditures by workers during the construction phase in local businesses, i.e. food and lodging, contributes approximately £11 million to the UK economy. This translates in to approximately 300 FTE jobs. (Biggar, 2012) By 2020 this could increase to:

- 0GW - £8 million and 200 jobs;
- 13GW - £14 million and 400 jobs;
- 15 GW - £18 million and 500 jobs; or
- 19GW - £27 million and 800 jobs.

The majority of these supported jobs are going to be located in rural areas where employment and economic development concerns are generally higher than in other parts of the UK. However, the degree of confidence one can place in these estimates is not high, due to a lack of clarity in how they were arrived at.

Wind farms have provided additional revenue streams and diversified sources of income for farmers and other land owners to support the continued viability of their businesses.

A wind farms benefits study of Aberdeenshire (northeast Scotland) has found that development of a single 0.8MW turbine scheme is likely to boost farm income by between £68,000 - £156,000 per year on average (SAC, 2010). However, there do not appear to be any studies which generalise these figures across the whole of Scottish farmland.

4.5 Government

4.5.1 Tax Base

The onshore wind industry currently contributes £198 million tax each year to the UK Exchequer including £59 million in non-domestic rates. (Biggar, 2012) This value excludes taxes associated with the distribution and sale of the electricity produced. By 2020, the sector could increase to:

- 10GW - £279 million including £130 million in non-domestic rates;
- 13GW - £373 million including £169 million in non-domestic rates;
- 15GW - £438 million including £194 million in non-domestic rates; or
- 19GW - £572 million including £247 million in non-domestic rates.

4.5.2 Business Rates[12]

The Basic Business Rate (also called Non-domestic rates) for Scotland in 2011 is 42.6% of the rentable value of property used in carrying out activities. For larger businesses with a rateable amount greater than £35,000 per annum a supplement of 0.7% is added which contributes to rate reductions or elimination for small businesses in Scotland.

In April 2010 Scotland initiated a targeted relief from Business Rates for renewable energy producers with discounts of up to 100%. The rational was that it will support the sector's importance in the climate change agenda and motivate further expansion of the sector. This relief will operate under State aid de minimis. (Scottish Government, 2011)

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[12] Business rates are a type of property tax normally collected by local government authorities and used to fund local services. It is a tax on the occupation of non-domestic property and is determined as a percentage of the annual rent the property would demand rather it is privately held or leased.

Table 4.5 Targeted Relief Schedule

Cumulative Rateable Value*	Percentage relief (%)
up to £145k	100
up to £430k	50
between £430k and £860k	25
between £860k and £4m	10
greater than £4m	2.5

*This will allow a business with 2 or more properties with a cumulative rateable value of under £25,000 to qualify for relief at 25% on individual properties with a rateable value less than £18,000.

The relief has saved the renewables industry about £4 million in 2011-12. Approximately 85 renewable energy properties currently benefit from the relief - and around 50 of these qualify for 100 per cent relief and pay no business rates at all. (Scottish Government, 2011a) Micro-renewables generation equipment is excluded from the valuation of a business property thus avoiding a disincentive for installation by businesses that are not-primarily engaged in the renewables generation. All offshore wind energy activities are completely exempted from rates. In England £12 million was pain for non-domestic rates in 2011. This value could increase to £27 million - £52 million by 2020, depending on which deployment scenario (10GW – 19GW) occurs. (Biggar, 2012) This income will be available to local authorities if a new proposed Local Government Finance Bill is approved by Parliament.

In order to increase the local economic benefits from new renewables, the current UK Government gave an election commitment over two years ago to allow communities that host renewable energy projects to keep the additional business rates the projects generate. The Department for Communities and Local Government (DCLC, 2012) has set out the UK Government's proposals to achieving this through a rates retention scheme:

- Business rates from new renewable energy projects would be retained in full by the relevant local authorities and would be disregarded in any re-set of tariffs and top ups and in the calculation of any levy
- Government would define – most probably in a statutory instrument – the types of properties to be treated as new renewable energy projects for the purpose of business rates

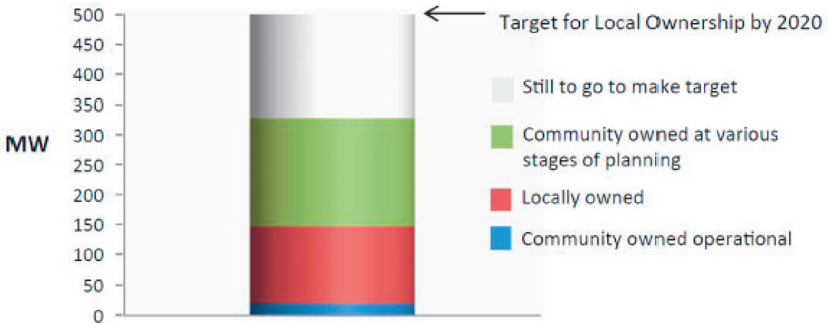
retention, using the criteria set out in a previous business rates statutory instrument2 as a starting point for such a list

- The definition would be framed in such a way as to enable developing renewable technologies to be covered by this scheme in the future as they come on stream
- Renewable power stations could include other non-renewable technologies as in practice other types of generation or use of property is likely to be minimal. As such, all rates from new renewable power stations should be retained in full

4.6 Rural and community development from locally owned RE projects

The Scottish Government has a goal for 500MW of renewable energy projects to be deployed and owned by local communities by 2020. The Government's objective is to maximise the benefits delivered to communities from renewable energy, beyond the energy generated and financial benefits. They believe that community owned and led renewables projects can increase community cohesion and confidence, skills development and support for local economic regeneration.

Figure 4.1 **Present state of community owned renewable energy projects**



Source: SCENE (2012).

Sustainable Community Energy Network (SCENE) has identified five principal benefits that community-led renewables developments can deliver:

- Electricity network resilience is increased by dispersion of renewables into local communities. Allowing electricity production to be controlled by local communities can avoid some of the challenges that come from intermittency and remoteness of generation assets. It can create areas of security during grid outages and contributing to voltage stability, all of which improves network resiliency. (Rogers, et al 2008; Strbac. Et al 2006; Hain, et al 2005)
- Community renewable energy projects provide economic, environmental and social opportunities; (Warren and McFadden 2010; Munday, et al 2011)
- Community ownership of renewable energy projects promotes greater energy efficiency and awareness of energy use; (Walker, et al 2006)
- Community ownership of local projects increases acceptance and assists in overcoming public opposition to renewable energy developments such as wind-farms, allowing for greater deployment levels; (Toke, et al 2008; Warren and McFadden 2010)
- Local communities can be a significant source of investment. Revenues generated from community-led renewables projects are often reinvested back into the renewables sector.

Scottish Community Energy Network has conducted an extensive survey of community oriented renewables projects in Scotland (SCENE, 2012). The research consisted of contact with community organisations that were involved in 314 community energy projects. They found that community ownership of renewables projects is expanding in Scotland with an estimated 180MW of generating capacity at various stages of the planning process in early 2012. From 2004 to 2011, about £35m has been invested into Scottish community-owned renewables, including £7m by communities themselves in the form of either community shares or capital reserves.

There are many non-financial benefits that accrue to society and the general economy from deployment of renewable energy projects. This is especially true of rural areas in Scotland that are seeking economic development. The financial cost of deploying community or farm based projects is expected to be significantly larger, on a per kW or MW basis, than large commercial scale projects because of economies of scale. Many costs of the permitting process and construction are the same regardless of project's scale, in addition to the level skill level and efficiency of the respective developers. Community renewable energy projects generally have lower economic efficiencies and provide a lower financial return on investments; these projects can be justified by financially viability but are rarely competitive with commercial projects. The non-financial benefits play a significant role in making the project worthwhile to the community.

Community energy development is progressing as a result of increased community interest but also from the financial investment and policy priorities of government. Scotland however has minimal community engagement in comparison to some other European countries. In Denmark 86% of total (onshore and offshore) wind energy capacity is locally owned; in Germany the rate is 50%. For Scotland, which has superior renewable resources, the ownership rate is just over 3%.

Deployment of projects is concentrated in northwest Scotland (Highland and Islands area) and is dominated by wind and hydro-electric installations. Integrated technology installations are dominated by solar photovoltaic, ground source heat pump, or micro-wind installations in combination with solar thermal panels in community facilities. One project included a wind-hydrogen fuel cell system; another is the integrated grid system such as the island grid developed by Eigg Electric. Biomass installations consisted exclusively of wood-fuel boilers based on logs or pellets. The table below indicates the portion of each technology in use or proposed.

Table 4.6 Technology types deployed in community projects, by count.

Technology	Percentage of Projects
Biofuel	0.40%
Air Source Heat Pump	0.80%
Ground source heat pump	1.50%
Anaerobic Digestion	1.90%
CHP - Biomass	3.10%
Integrated	3.10%
Solar Photovoltaic	7.70%
Solar Thermal	8.50%
Biomass	9.60%
Hydro	18.10%
Wind	45.40%

Source: SCENE (2012)

Projects that currently exist and are operating were highly dependent on grant funding, which contributed an average of 33% of total project costs. Charitable and non-governmental support has diminished in recent years with current projects at early feasibility stages relying on CARES loans[13] (CARES, 2012) and/or community shares to source seed capital. This follows a reduction in the availability of grant funding and new government regulations on the incompatibility (redundancy of funding issues) between feed-in-tariffs and public grants to cover capital costs.

Community-led wind power development costs average £4,609/kW as compared to £2,466/kW for joint ventures. This disparity is likely to reflect economies of scale, as well as factors such as the increased cost of debt finance and lengthier periods of project development faced by community organisations. The time-scale from conception to completion of community-led ventures exceeding 50 kW ranged from 1 to 8 years, averaging at just slightly over 4 years.

The primary reasons Scottish communities reported for engaging in renewable energy projects are (SCENE, 2012):

- Generate local income and strengthen the local economy 48%

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[13] CARES Loan Funds are administered by Community Energy Scotland who is responsible for delivering these Scottish Government funds. The main focus of the funds is to reduce the barriers to community or local rural business entrepreneurs who want to test and develop additional renewable energy generation projects.

• Decrease the community carbon footprint and/or increase energy awareness	17%
• Lower energy costs	15%
• Secure local control over aspects of an already planned commercial project	4%
• Increase the community's self-sufficiency	6%
• Increase availability /reliability of electricity supply	3%
• Other	6%

SCENE examined the level of opposition encountered to community renewable energy projects. With there being no or very limited opposition:

There have been no objections voiced against the project	64%
One or two individuals in the community have voiced concern	23%
One or two people in the community object strongly	5%
Several people in the community object strongly	5%
There exists an organized campaign from within the Community against the project	3%

4.6.1 Community funds

The most common method for private sector renewable energy developers to provide community benefits is for financial resources to be paid into a fund for use by the community. There are different ways to connect the renewables project to the financial and non-financial resources given to the community. The most common practice in Scotland is for the size of contributions to be correlated to the scale of the project. The scale can be either a physical attribute like total MW of a project or the number of turbines or, less rarely, the number of people adversely impacted by construction and operation. Whichever criteria is used, an agreed payment to the community fund is made, typically annually for the life of the project. Annual payments linked to the size of the project are simple and create certainty for the project owner. Lump sum payments are less common but are used if developers do not want on going financial commitments to the community. Payments typically occur when the project starts operating, or at some other predetermined benchmark.

Another format for determining the level of funding is for the payments to linked to the revenue or profits generated by the project. This method reduces the financial risk for the wind farm developer. It also creates the strongest link between the community benefits and the benefits being generated by the wind farm. The community does face increased risks of funds being delivered if there are poor performance issues or low renewable electricity prices.

4.6.2 Benefits in kind

There may be civic improvements that would benefit the local community which are a renewables developer can deliver directly as part of the construction process instead of contributing to a fund. Potential improvements could include local facilities, environmental improvements, tourism or recreational provision, telecommunications improvements, among many other alternatives.

These benefits in kind need to be clearly separate and in addition to those actions which the renewables developer is required or ordered to deliver as mitigation for adverse impacts of the development.

4.6.3 Local ownership

Local ownership can take two principal form; local residents of a community who invest private funds in a local for-profit renewable energy project, or a project is developed by an organisation that is explicitly trying to capture benefits for the community. Either investment form will increase the likelihood that more of the benefits will be retained in the community, compared to projects with external ownership. If the former occurs there will be additional income earned by individuals within the local community. If the latter form is developed all profits are available for the community organisation to invest or distribute as it sees fit.

There is one additional form that typically requires larger scale projects. The renewable energy developer grants a portion of the project ownership to the local community. The local community than receives dividend payments from the distributed profits of the project. This structure is similar to the community fund method mentioned above; however there are potential risks and liabilities attached to by actual share ownership.

4.6.4 Local contracting and procurement

Onshore wind farms construction costs are currently in the £1,000,000 – £1,200,000 per MW range. The annual cost of operating and maintaining are in the £12,000-£15,000 per MW range. The portion of benefits arising from these expenditures that can be retained in the local community is very locational dependent. Projects that are closer to population centres that can provide manufacturing, services or the required skilled labour are more likely to contract or procure locally.

EU regulation and UK procurement laws do not allow for renewable energy developers to guarantee that contracts will be issued to local companies, especially for large scale developments.
On average approximately 15 - 20% (£150,000 – 180,000 per MW) of the cost of onshore wind energy development is for work which requires skills typically available from contractors found in most parts of the UK. The types of work include supplying and pouring concrete, laying cables and basic civil engineering tasks (e.g. tracks and hard-standing, foundations, trench digging for cables, basic construction of sub-station housing). Operating and maintaining wind farms is not labour intensive; it is also a specialist business. Nevertheless, for larger developments, there may be opportunities for the wind farm owners to encourage operation and maintenance (O&M) contractors to recruit and train locally for the additional staff they will need for a large new project.

4.7 Conclusion

Renewable energy projects in general and onshore wind energy projects specifically have not been financially viable to this date. However, there are many benefits that can accrue to society and to an economy from the deployment of wind farms. With sufficient subsidies and regulatory support the projects can be viable and constructed, and the secondary benefits manifest. Substantial employment and economic growth can be created by the development or expansion of a new onshore industry as the supply chain is developed. Although employment growth is not normally incorporated in a cost-benefit analysis as such the value of the additional economic activities are included. The national tax base, as well as local or regionally, can be increased as high value commercial scale wind projects are built. This can become an important new revenue source for sub-national governments in rural areas of a country. Development of community energy projects can be a catalyst for non-financial benefits like social inclusion and cohesion, awareness of energy and climate change concerns, environmental conservation, in addition to on-going revenues produced by the project.

5 Measuring the environmental benefits and costs of renewable energy

Investing in renewables can generate both positive and negative impacts on the environment. Amongst *positive* impacts are reductions in local air pollutants (such as particulates) and regional pollutants such as SO2 and NOx (due to the displacement of power generation from fossil fuel sources). Displaced CO2 emissions count as a reduction in global damages, so long as this displacement consists of an actual decline in emissions rather than a re-allocation of emissions between sources (see below).

But *negative* impacts can also arise: for example, the impacts on salmon fisheries from damming rivers for hydro power; the impacts on landscape quality from the construction of on- and off-shore windfarms; and the effects on carbon storage in peatlands due to windfarm construction.

These impacts are mainly not priced by markets due to the problem of missing markets (one type of market failure) referred to in Section 2. In this section, we describe the types of environmental impacts which renewables can have, and how these can be measured in monetary equivalents (krone, euro..); and then review some recent studies which have tried to estimate such impacts.

First, we deal with positive externalities, then with negative externalities. A section on public willingness to pay for green energy is presented, and finally an example is given which pulls all these types of effect together.

5.1 Positive Impacts

The positive environmental impacts of renewables are the avoided pollution from fossil fuel generation due to the displacement of generation by coal, oil or gas burning to generate electricity. The environmental effects of pollution from fossil fuel combustion in power stations have long been studied. These effects include:

- Increased mortality and morbidity due to higher concentrations on particulates, linked to chest and heart problems;
- Ecological effects on water quality due to acidification
- Ecological effects on heathlands due to sulphur and nitrogen deposition
- Damages to agricultural crops, particularly where SOx and NOx react to form low-level ozone
- Impacts on historic buildings.
- CO2 emissions contributing to global climate change

The ExterneE study (1995) represents an early, comprehensive assessment of these damages in physical terms, and a review of what was known in the mid 1990s about the economic costs of such impacts (EC, 1995; AEA Technology, 2005). This study, replaced by the NewExt project in 2005, was partly a search for estimates of marginal damage costs which could be added to marginal production costs to show the true social costs of using fossil fuels to provide energy in Europe. In fact, the air pollution impacts from NOx, SOx and particulates have been studied in environmental economics since the mid 1970s. Estimates of these marginal damage costs from AEA (2005) are shown below in Table 5.1. The figures shown include health impacts and ozone effects on agriculture, but not ecological impacts, which were judged to be too difficult and too case-specific to quantify in this way.

Table 5.1 POINT ESTIMATES OF EXTERNALITY COSTS FOR AIR POLLUTION in 2005 euro/tonne

Pollutant:	UPPER	LOWER
NH3:	31000	11000
NOx	12000	4400
PM2.5	75000	26000
SO2	16000	5600
VOCs	2800	950

Source: taken from AEA Technology (2005)

Note: VOCs = volatile organic compounds

Amongst the techniques used to evaluate these effects have been the following (Table 5.2):

Table 5.2 TYPES OF IMPACT WHICH COULD BE COSTED

Category of impact	Type of effect studied	Methods available
Health effects: increased mortality and morbidity	Deaths brought forward by low urban air quality; increased illness rates amongst those with chest problems.	See text below: Value of Statistical Life (VSL) or Value of Statistical Life Year (VOLY) can be used to calculate value of avoided/additional fatalities; willingness to pay for avoided health effects can be used; avoided costs from hospital treatment can also be measured.
Ecological impacts on water quality or heathland	Acidification of upland streams and lakes; changes in vegetation in upland heaths	Predominantly stated preference approaches (eg MacMillan and Hanley, 1996), but revealed preference travel cost models could link changes in consumers' surplus from recreational fishing days with ecological impacts.
Damages to agricultural crops	Impacts of low-level ozone on crop yields	Extensively studied in 1980s and early 90s using production function methods, based on dose-response relationships between crop yields and air pollution. Hanley and Spash (1993) give examples from this literature.
Damages to historic buildings	Damages in terms of erosion of stonework, and blackening	Could use avoided cost approach (the costs of building cleaning and restoration), but a stated preference approach could also be used, which measures public willingness to pay to avoid such damages (see Pollicino and Maddison, 2001)
Climate change impacts	Contributions to future climate impacts over time	See text below: integrated assessment models combined with damage cost estimates.

Health effects are typically costed having divided cases into increased mortality (deaths brought forward) and increased morbidity (higher incidence of non-fatal illness). For increased mortality, economists have used Value of a Statistical Life (VSL) estimates based on stated preference (eg contingent valuation of reductions in risk of death) and revealed preference (eg by studying wage differentials due to differences in on-the-job risks). These stated- and revealed-preference estimates of VSL can be converted into per life year figures (VOLY), since deaths are typically brought forward by air pollution, and since research has shown that the VSL varies according to age. Many criticisms have been levied at the concepts of the VSL and VOLY (Baker et al, 2008; Cameron, 2010). However, governments continue to use such figures in the assessment of transport policy, for example. For increased morbidity, willingness to pay estimates can once again be used, based on people's willingness to avoid an increased chance of a non-fatal illness. For example, the US EPA uses a figure of $300,000 per avoided case of bronchitis. Avoided health service costs can also be used, but these do not represent a welfare-consistent figure, since they do not take into account the distress and inconvenience of illness. Health effects from coal combustion in particular have long been associated with increased mortality and morbidity (Fouquet, 2011), and numerous studies undertaken to quantify these impacts in monetary terms (eg Cropper at al,1997; Maddison and Gardner, 2002; Muller and Mendelsohn, 2007).

Climate change impacts per tonne of fossil fuel are harder to estimate, due to the complex linkage between CO2 emissions from a power station, and future impacts from changing climate. Typically, such damage costs are calculated using integrated assessment models, which link predicted changes in climate to economic activity, for example through computable general equilibrium modelling. "Consensus" estimates of damage costs per tonne of CO2 equivalent have been reviewed in many studies, such as Stern (2006), World Bank (2011) and Tol (2005). These vary according to assumptions made as to the extent of physical impacts, their timing and the discount rate. The studies reviewed by Tol (2005) had a mean marginal social cost of carbon of $25 US per tonne CO2; World Bank (2011) use a figure of around $7 US. Many countries have now adopted standard values for carbon pricing, sometimes referred to as a social cost of carbon[14]. For example, the UK government employs a "shadow price of carbon" of 25 UKP per tonne CO2e in 2007, rising to 59 UKP per tonne in 2050. This reflects a target of a maximum of 550 ppm concentration stabilisation trajectory.

How could such impacts be included in a cost-benefit analysis? If a renewable energy investment avoids 1,000 tonnes of SO2 and 50,000 tonnes of CO2 being emitted from a coal fired power station for the next 15 years (as the renewable investment allows this coal fired station to be closed), then the environmental benefits of this action in any year would be equal to:

{1,000 x cost per tonne of SO2 in health and ecosystem etc damages} + {50,000 x cost per tonne of CO2 damages}, multiplied by the discount factor for the year in which these damages are avoided.

So if we take a CO2 damage cost figure of 20 euro /tonne, and a SO2 price of 1400 euro/tonne, then before discounting, the environmental benefits per year from avoided fossil fuel pollution are (1,000 x 1400) + (50,000 x 20) = 2.4 million euro per year. This figure would then be discounted over the lifetime of the renewable energy investment: here, 15 years. This constitutes a benefit of investing in renewables, which can be added to the (market) value of the electricity generated.

However, it is important to note that the presence of government policies to regulate and/or price externalities may complicate the inclusion of avoided pollution damage costs in a CBA. Suppose the government has already placed a tax on emissions of SO2 or NOx, and that this tax was exactly equal to the marginal damage costs per tonne of these emissions. If this was the case, then the price of electricity would already include the value of external damages. In such a situation, the generation portfolio would also reflect the marginal social costs of alternative sources. Such a complete internalisation of externalities is not something we observe in the real world. Countries such as Sweden do tax certain air pollutants (including SO2 and NOx), but these

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[14] Defined in DECC (2007) as "The social cost of carbon (SCC) measures the full global cost today of an incremental unit of carbon (or equivalent amount of other greenhouse gases) emitted now, summing the full global cost of the damage it imposes over the whole of its time in the atmosphere"

taxes do not reflect the full social costs of damages. In this case, there is still a need to account for the avoided environmental damages of lower emissions from displaced power sources.

A second issue relates to situations where CO2 emissions from a sector are constrained by law. For example, if a country sets a limit on total emissions from the electricity sector, then closing down a coal burning power station due to the construction of several off-shore windfarms will reduce CO2 emissions from that power station, but CO2 permits can then be sold on to other generators. In this case, whilst the price of CO2 permits might conceivably change, there is no change in the level of CO2 emissions from the sector.

5.2 Negative Impacts

Renewable energy investments can have a range of negative impacts on the environment, which can be costed for inclusion in a cost-benefit analysis. These negative effects include the following:

Hydro Power

- There are well-known conflicts between salmon fishing and managing rivers for hydropower. Hydro management changes flow rates (eg downstream of a dam) and creates physical barriers to fish migration and movement.
- Impacts of dam construction on wilderness quality
- Erosion of river banks due to changes in flow rates

On-Shore wind farms

- Wind farms create impacts on the quality of landscape which may be negative for many citizens
- Wind farm construction in peatland areas can displace much stored carbon via erosion, and lead to atmospheric losses of carbon (van der Wal et al, 2010).
- Wind turbines can have negative impacts on birds and bats (Park, 2012)

Off-shore wind farms

- Vidual dis-amenity to those living or visiting the coast, dependent on distance off-shore at which turbines are located
- Effects on sea birds
- Construction impacts on marine ecology

Biomass plants

- Air pollution

Economists have been building up a body of empirical studies which tries to measure these negative impacts in monetary terms. Some of the earliest applications of non-market valuation, in the context of CBA, were to the impacts of hydro power development in the US – including Krutilla and Fisher's landmark work *The Economics of Natural Environments*, and work by John Loomis (Loomis et al, 1986).

Beginning in the late 1990s, a new impetus came in this work, starting with work on windfarms and hydro in Denmark and Norway. In what follows, we present some examples from 2002 onwards, arranged according to which renewable technology was targeted or whether multiple technologies were considered. Most recent papers have focussed on wind energy, rather than hydro, biomass or wave power.

5.2.1 WIND ENERGY: OFF-SHORE

McCartney (2005) investigated the preferences of citizens regarding a proposed wind farm off the coast of Jurien Bay Marine Park, Australia. The study sought to establish the visual amenity value of both the coastal interface with the sea, which included sand dunes in this area, and the sea itself, by asking how much respondents would be WTP to move an offshore wind farm further inland. The paper finds that there is no significant difference in the WTP for these two distinct views. The net WTP to preserve the coastal interface view was AU$36.15 per household, per year and AU$34.30 per household, per year to preserve the sea view. The author also found that although the net estimate of WTP was significant and positive, there existed a significant negative WTP for a sub-sample, indicating that some people would welcome a change to the seascape view.

In Europe, Ladenburg and Dubgaard (2007) estimated WTP for reducing the visual dis-amenities from future offshore wind farms using a Choice Experiment. The valuation scenario comprises the location of 720 offshore wind turbines (equivalent to 3600MW) in farms at distances equal to 12, 18 or 50km from the shore, relative to an 8 km baseline. Average willingness to pay amounts were estimated as 46, 96 and 122 Euros/household/year for having the wind farms located at 12, 18 and 50km from the coast as opposed to 8 km. The results also reveal that WTP varies significantly depending on the age of respondents and their experiences with offshore wind farms. In a follow up study based on an internet panel of Danish citizens, Ladenburg (2010) finds that attitudes to wind farms are conditioned by the frequency and type of coastal recreation visits, and by experience with on-shore wind farms, indicating the potential for a high degree of variability in the valuation of aesthetic externalities between positive and negative values. A similar degree of variation in attitudes towards wind power (although this time both for on-and off-shore wind) can be found for Sweden in Ek (2005). In France, Westerberg et al (2011) consider the effects of off-shore windfarms on tourism in the Languedoc Rousillon coastline, in context with other local environmental investments designed to reduce carbon emissions. The study concludes that wind farm construction 12 km offshore is preferable from the viewpoint of favouring the tourist industry. The external costs of locating wind farms 5, 8 and 12 km from the shore are approximately €115, €50 and €0 per household per year on average across 3 latent class models. With simultaneous application of a coherent local environmental policy and wind farm associated recreational activities, a wind farm could be established from >5 km without causing negative externalities.

In the USA, Krueger et al (2011) distributed a Choice Experiment to 3 stratified random samples (bordering Delaware Bay, bordering Atlantic coast and inland) in Delaware (U.S.) by mail, investigating the WTP to prevent visual disamenities from offshore wind farms. The attributes included in the CE were: location, distance from the shore and energy company royalty payments to community fund. The main result of the study was that households bordering the Atlantic coast were WTP more than households bordering Delaware Bay, who in turn were WTP more than inland households. The annual cost to inland households was $18.86, $8.74, $0.78 and $0 for wind farms located 0.9, 3.6, 6 and 9 miles off the coast, respectively. The equivalent costs to households in Delaware Bay were $34.39, $11.17, $5.83, $2.05 for wind farms located 0.9, 3.6, 6 and 9 miles off the coast, respectively, whilst for households on the Atlantic coast the figures were $80.03, $68.79, $35.10, $26.65 for wind farms located 0.9, 3.6, 6 and 9 miles off the coast, respectively. This translates into households being WTP $12 for each additional 0.25 miles their home is located away from the Delaware coast. The study concludes that the magnitude of the decrease in external costs imposed as the turbines are moved from 6 to 9 miles off the coast, suggest that it may be cheaper to compensate households for the visual disamenity at 9 miles off the coast than it would be to move the turbines further off the coast so that they are not visible, since this would imply much higher construction costs.

5.2.2 WIND ENERGY: ON-SHORE

In an early study, Alvarez-Farizo and Hanley (2002) employed both contingent ranking (CR) and choice experiment methods for eliciting preferences for the construction of wind farms on La Plana in northern Spain. The CR and CE each consisted of attributes descrtibing impacts on cliffs, impacts on fauna and flora, and impacts on landscape and cost. The environmental impact attributes have two levels: protected and damaged. The cost attribute (specified as local taxes) had 3 levels: 500, 1000 and 1500 pesetas (PTA). Respondents were given information on electricity production from renewable resources as well as information on the potential effects of wind farms. They are also shown pictures of the current landscape and manipulated photos of the future landscape should there be further development of wind farms. The survey was administered December 1998 in Zaragoza. Both methods were used to calculate which impacts of windfarm construction imposed the highest costs on residents of Zaragoza. Impacts on flora and fauna turned out to impose the highest costs, compared to impacts on landscape quality.

Groothius et al (2008) estimate the Willingness to Accept compensation (WTA) of locals for a wind farm proposed in the southern Appalachian highlands of North Carolina. They calculate a median WTA of $23 per household per year for the installation of a wind farm in a local scenic area, with a 95% WTA confidence interval of $5 to $39 per household per year. Grossing up the median WTA by the number of households in the area (18,540) suggested that a total payment of $426,400 to those affected in the local community would be required to give the project popular support. The authors argue that compensation can be used to overcome NIMBY objections. The study also found that individuals with concern for the environment required less compensation than average to compensate for windfarm construction.

A similar WTA study is that by Dimitropoulos and Kontolean (2009) in Greece. This study used a CE to establish the public's WTA for wind turbine installations on the islands of Naxos and Skyros using face to face interviews. The attributes included in the study were: the number of the turbines, turbine height, conservation status of the installation site, the degree of local involvement in the planning process, and the annual subsidy received per household as compensation. The mean WTA to reduce the wind farm size from 30 turbines to 4 was €1128 per household per year in Skyros, but only €282 per household per year in Naxos. The mean WTA to reduce turbine height from 90m to 50m was €243 and €510 per household per year in the pooled (both islands) models. The mean WTA to move the wind farm from a protected nature site to an unprotected site was €719 and €2,090 per household per year for each island respectively. Finally, the mean WTA to include locals in the planning process was between €855 and €1,056 per household per year. The authors note that these figures appear to be very high, which they suspect is due to the use of a WTA format.

Indeed, more studies have used a WTP format to assess externalities from on-shore wind. Meyerhoff et al (2010) use two CEs, in Westsachsen and Nordhessen (Germany), to determine the WTP for improved environmental outcomes associated with onshore wind farms. The attributes included in the study were: reductions in Red Kite populations (a bird whose presence in the area was threatened by wind farm construction), reduction in number of wind turbines in a wind farm, reductions in height of wind turbines and increased minimum distance of wind farms from home. Using a conditional logit model, the authors report that respondents were WTP significant positive amounts to protect Red

Kite populations and to increase the minimum distance wind turbines are placed from homes (€3.18 per household per month to increase minimum distance from 750m to 1,100m and €3.81 per household per month to increase minimum distance from 750m to 1,500m). No significant WTP was found for changes in the number of wind turbines and for wind turbine height. The authors state that this may be due to the lack of photographs accompanying what was a telephone survey. The main purpose of the study was to compare the results of the standard conditional logit model with a latent class model. The authors settle on using 3 segments, people within each group being labelled as advocates, opponents and moderates with regard to wind power. The advocate group was the largest segment (40%) in Westsachsen, while the opponent group was the largest segment (44%) in Nordhessen. The only attribute which was significantly different across both regions was the minimum distance wind turbines would be placed from homes. In both regions the opponent group was WTP significantly more (up to €120 per household per year in Westsachsen) to increase the minimum distance wind turbines were placed from homes, compared to €0 in the Nordhessen advocate group.

5.2.3 COMBINED ENERGY SOURCES

Several stated preference studies have investigated preferences for a range of renewable and non-renewable technologies, and have included some environmental impacts of renewables in their design.

One example is Bergmann et al (2008) for Scotland. They use a CE where the attributes used were landscape impacts, wildlife impacts, air pollution (eg from biomass), local employment created, and price. Technology labels were not used in the design; rather, two renewable alternatives, described using these attributes, were included in each choice card along with a fossil fuel alternative for future energy policy in Scotland. Analysis of the data showed that (i) respondents preferred any renewable option to the fossil fuel option; (ii) that high landscape impacts and effects on wildlife generated significant negative costs on respondents; (iii) that employment consequences were insignificant impacts for the general sample and that (iv) variations in education level and age influenced choices. The authors then divided the sample into urban and rural respondents, and ran separate choice models for each. They found big differences in preferences towards renewables between the two groups, implying a very unequal distribution of benefits and costs. Finally, the authors calculate WTP for the average, for urban, and for rural respondents of alternative renewable investments (a large offshore windfarm; a large onshore windfarm; a small onshore windfarm; a biomass plant) described by these attributes. They find that there are big differences in the benefits of these different investments to rural and urban households, partly driven by expectations over local employment effects.

A second example is Tinch and Hanley (2011). Based again on a sample of Scottish households, the authors use a choice experiment which looked at different energy options in terms of a number of attributes. Each of the power generating options in the experiment was described in terms of the following attributes:

- *Distance from respondents' home* – the distance from the respondent's home to newly built generation sites.
- *Carbon Emissions Reduction* - the reduction in emissions that future energy options can provide in relation to 20% of the UK's electricity generation.
- *Local biodiversity* – the impacts on local number of species of birds, mammals, insects or plants.
- *Total land* – the amount of land occupied by the energy option all over the UK in order to produce 20% of total UK's electricity.
- *Annual Increase in Electricity Bill* – the amount by which each household's annual energy bill will increase.

An example of the choice cards used is shown below:

EXAMPLE Card				
Characteristics	**Option 1 Electricity from WIND**	**Option 2 Electricity from BIOMASS**	**Option 3 Electricity from NUCLEAR**	**Option 4 Current Energy Mix**
Distance from Home	6 miles *[10km]*	0.25 miles *[400m]*	1 mile *[1.6km]*	18 miles *[29km]*
Local Biodiversity	Less	More	No Change	Less
Carbon Emissions for producing 20% of UK electricity	Reduction by 99%	Reduction by 50%	Reduction by 95%	Reduction by 0%
Total Land for producing 20% of UK electricity	5,832 ha *Or 7,930 football fields*	816,000 ha *Or 1,190,750 football fields*	568 ha *Or 772 football fields*	1,594 ha *Or 2,167 football fields*
Annual Increase in Electricit Bill	**£143**	**£40**	**£67**	**£0**
Please tick your preferred option	☐	☑	☐	☐

The survey was sent out to a sample of 1000 households across Scotland. Participants were chosen randomly based on the 2008 Electoral Register Database. Three weeks later a reminder containing another copy of a questionnaire was sent out to all non-respondents. After accounting for returned/undelivered questionnaires, 245 usable or partially usable responses were received – a total response rate of 27%. This is very similar to other mail-shot choice experiments in Scotland.

Results suggest that people consistently identify distance, an increase in biodiversity and a reduction in emissions as the most significant attributes. These variables come through as significant at the 5% level and have positive preferences associated with them. Standard deviations for distance and reduction in emissions attributes come through as significant at the 5% level, which suggests the existence of heterogeneity in the parameter estimates over the sampled population. As expected, people prefer to live further away from power generation stations, wish to see an increase in biodiversity and have positive preferences towards a reduction in carbon emissions. At the same time they have strong negative preferences towards increases in their annual energy bill (the cost attribute was negative and significant at the 1% level). Interesting results were observed with regards to public attitudes towards alternative specific constants (the "technology labels" in the choice card above), in that respondents in the total sample displayed positive attitudes not only towards wind, but also towards the nuclear energy option compared to the current generation mix (alternative specific constants are positive and significant at 1% and 5% levels respectively). Tinch and Hanley also found very considerable variation in these results if respondents were split according to which part of Scotland they lived in (Southern, Central, Highlands and Islands), as shown in the following table.

Table 5.3 Willingness to Pay Estimates - Regional Analysis from Tinch and Hanley (2011)

Variable	**Central**	St. error	t-stat	**South**	St. error	t-stat	**Highlands and Islands**	St. error	t-stat
Distance	4.64*	2.74	1.69	5.83***	2.10	2.77	£0.35	2.81	0.13
Biodiversity-no change	-£20.88	19.31	-1.08	£15.00	14.87	1.01	-£9.96	22.75	-0.44
Biodiversity-more	£26.54	80.94	0.33	-£0.27	34.47	-0.01	113.41*	62.76	1.81
Emissions reductions	£1.41	0.90	1.58	1.51**	0.73	2.05	-0.09	0.88	-0.11

Note: ***, **, * = Significance at 1%, 5%, 10% level. Shaded cells show willingness to pay significantly different from zero. Values are in UK pounds per individual per year. Splitting the sample in this way greatly reduces sub-sample size, and contributes to higher standard errors in WTP estimates.

People in the Highlands and Island seemed to identify increased biodiversity as the most valued attribute, whereas distance from respondent's home comes through as significant for people in the Central region. For the respondents in the 'South' the attributes distance and reduction in emissions come through as highly significant (at 1% and 5% levels respectively). Given that Glasgow and Edinburgh, the two largest and highly populated cities in Scotland, are included in this group, such preference towards these two particular attributes seems logical. This spatial variation in preferences has implications for the political acceptability of different renewable energy options across the country.

5.3 Willingness to pay for the “green” nature of renewable energy

Several studies have been undertaken to estimate people’s willingness to pay for renewable energy relative to fossil-fuel derived energy. Such studies show the analyst what values should be used for the benefits of projects which produce renewable power.

An early example is Roe et al (2001) for the USA. Roe at al compare choice modelling results from surveys of electricity consumers as to their WTP a higher price for green energy with hedonic price estimates of the actual premium paid in parts of the US. In the choice modelling exercise, respondents were offered hypothetical supply options differentiated in terms of price (monthly bill), contract terms, fuel mix and pollution emissions relative to the regional average. The results showed that the premia people said they were WTP were small (around $0.50 increase in annual bill at most for the biggest reduction in pollution considered), and varied by socio-economic grouping and by region.

The authors also analyse market data from 21 green supply deals available in 2000 to US consumers. These showed price premia ranging from -$102 to +$263 per year, with a median of $59; these numbers relate to a great variation in the % of “new” renewables included in the supply package. The authors then undertaken a linear regression to explain the variation of these price premia in terms of % generation from all renewables, % generation from new renewables, whether the scheme is certified under the “Green-e” scheme, and the geographic region in which the scheme operates. If one interprets the choice modelling results as showing WTP for new renewables supply, then the real market data marginal effect of a $6 per annum price premium for a 1% increase in new renewables lies within the range of estimates for an equivalent change for the stated preference data. Other applications of stated preference methods to WTP for green electricity in the US are Champ and Bishop (2001) and Poe et al (2002).

Menges et al (2005) undertook a similar study for Germany. The baseline scenario was 100% of electricity being supplied by fossil fuels. Respondents were asked to state how much they would be willing to donate (WTD) for increasing proportions of renewable and nuclear energy. They found that respondents were WTD €24 for a 25% reduction in fossil fuels, €40 for a 50%

reduction, €52 for a 75% reduction and €68 for a 100% reduction in fossil fuel sourcing. Including nuclear alongside renewable sources, as an option to reduce fossil fuel usage reduced the WTD by approximately €15 for each scenario. A different approach is followed by Borchers et al (2007) for the US. They use a Choice Experiment to estimate consumer preferences and WTP for voluntary participation in green energy electricity programs. Solar power was preferred to wind power and a generic green label at the 10% level of significance. Mean WTP for the generic green label voluntary program was $15 for 10% of energy from renewable sources and $17 for 25% of energy from renewable sources. The exact same question was the asked, in the context of a mandatory rather than voluntary program. This reduced the mean WTP for the generic green label program to $8 for 10% of energy from renewable sources and $12 for 25% of energy from renewable sources.

Longo et al (2008) undertake a rather different analysis for England, using a choice experiment with greenhouse gas emission reductions, security of supply (expected number of black-out minutes per year) and employment in the energy sector resultant from a national increase in renewable energy as the attributes. They find statistically significant WTP estimates for each of these attributes. For example, the average respondent is willing to pay £29 per household per year for a 1% national reduction in greenhouse gas emissions through investment in renewable energy. These implicit prices depend on respondents' education levels and whether they have children.

5.4 Combining costs and benefits – an example

We now provide a simple example which makes use of the kinds of values described in sections 5.1, 5.2 and 5.3.

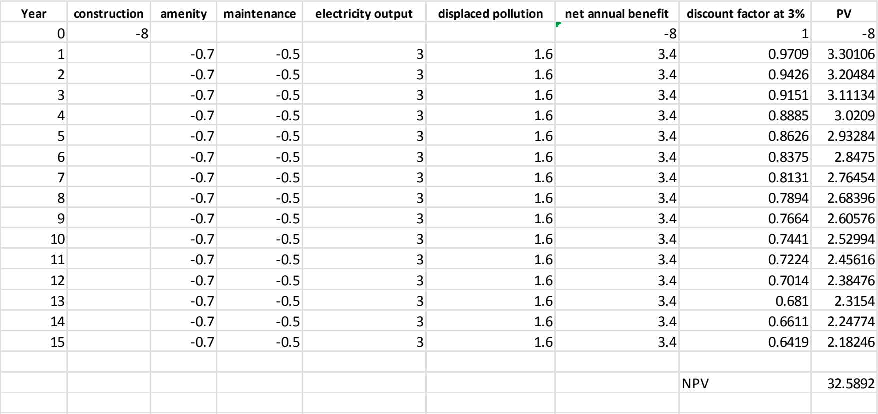
Consider the following. A new offshore windfarm is proposed, however, there are two options for where to site it, namely 1 mile offshore or 20 miles offshore. The main external cost is a visual dis-amenity effects on (i) tourists and (ii) locals. No significant effects on marine wildlife or sea birds are anticipated. A contingent valuation study shows that public WTP to avoid the dis-amenity is higher, the closer the windfarm is to the shore. Siting the windfarm close to shore means lower construction and cabling costs, although at the expense of some potential power output. Either wind farm would result in the displacement of SO2 and CO2 from a coal-fired power plant. The value of electricity outputs are calculated based on consumers' willingness to pay for "green" electricity.

An analysis might show the following, assuming a project lifetime of 15 years:

Table 5.4 Input data for a CBA of off-shore wind energy

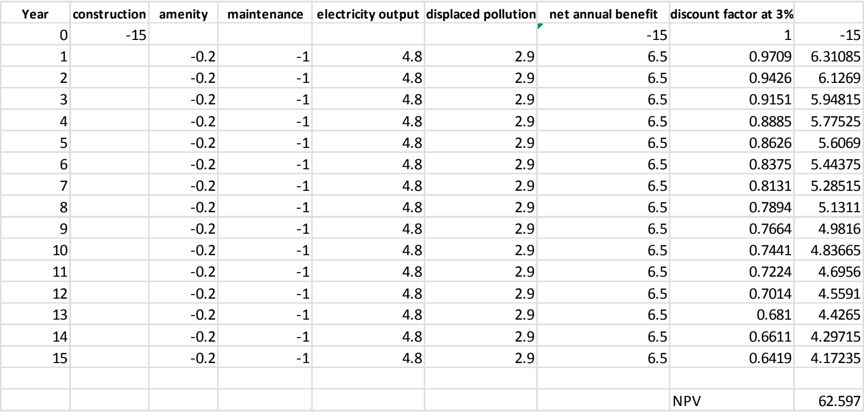
	1 mile off-shore	20 miles off-shore
Construction and cabling costs (year 0)	8 million euro	15 million euro
Maintenance costs (years 1-15)	0.5million euro	1 million euro
Power output per year (years 1-15)	500 Mw	700 Mw
Annual value of electricity output	3 million euro	4.8 million euro
Dis-amenity costs, based on aggregate willingness to pay of tourists and residents to avoid landscape impact: (years 2-15)	0.7 million euro	0.2 million euro
Avoided damage costs	1.4 m + 0.2 m = 1.6 m euro	2.4 m + 0.5 m = 2.9 million euro

If a discount rate of 3% is used, then this reveals the following for the 1-mile offshore wind farm:



Year	construction	amenity	maintenance	electricity output	displaced pollution	net annual benefit	discount factor at 3%	PV
0	-8					-8	1	-8
1		-0.7	-0.5	3	1.6	3.4	0.9709	3.30106
2		-0.7	-0.5	3	1.6	3.4	0.9426	3.20484
3		-0.7	-0.5	3	1.6	3.4	0.9151	3.11134
4		-0.7	-0.5	3	1.6	3.4	0.8885	3.0209
5		-0.7	-0.5	3	1.6	3.4	0.8626	2.93284
6		-0.7	-0.5	3	1.6	3.4	0.8375	2.8475
7		-0.7	-0.5	3	1.6	3.4	0.8131	2.76454
8		-0.7	-0.5	3	1.6	3.4	0.7894	2.68396
9		-0.7	-0.5	3	1.6	3.4	0.7664	2.60576
10		-0.7	-0.5	3	1.6	3.4	0.7441	2.52994
11		-0.7	-0.5	3	1.6	3.4	0.7224	2.45616
12		-0.7	-0.5	3	1.6	3.4	0.7014	2.38476
13		-0.7	-0.5	3	1.6	3.4	0.681	2.3154
14		-0.7	-0.5	3	1.6	3.4	0.6611	2.24774
15		-0.7	-0.5	3	1.6	3.4	0.6419	2.18246
							NPV	32.5892

For the 20 mile offshore plant, we get:



Year	construction	amenity	maintenance	electricity output	displaced pollution	net annual benefit	discount factor at 3%	
0	-15					-15	1	-15
1		-0.2	-1	4.8	2.9	6.5	0.9709	6.31085
2		-0.2	-1	4.8	2.9	6.5	0.9426	6.1269
3		-0.2	-1	4.8	2.9	6.5	0.9151	5.94815
4		-0.2	-1	4.8	2.9	6.5	0.8885	5.77525
5		-0.2	-1	4.8	2.9	6.5	0.8626	5.6069
6		-0.2	-1	4.8	2.9	6.5	0.8375	5.44375
7		-0.2	-1	4.8	2.9	6.5	0.8131	5.28515
8		-0.2	-1	4.8	2.9	6.5	0.7894	5.1311
9		-0.2	-1	4.8	2.9	6.5	0.7664	4.9816
10		-0.2	-1	4.8	2.9	6.5	0.7441	4.83665
11		-0.2	-1	4.8	2.9	6.5	0.7224	4.6956
12		-0.2	-1	4.8	2.9	6.5	0.7014	4.5591
13		-0.2	-1	4.8	2.9	6.5	0.681	4.4265
14		-0.2	-1	4.8	2.9	6.5	0.6611	4.29715
15		-0.2	-1	4.8	2.9	6.5	0.6419	4.17235
							NPV	62.597

So the Net Present Value of the 20 mile offshore project is higher than that off the 1-mile offshore project, despite its higher capital and maintenance costs, due to the combination of higher values for displaced pollution and lower dis-amenity costs. A CBA analysis would recommend that both projects be undertaken, since both have a NPV > 0; but if some reason a choice must be made, then the 20 mile offshore project is preferred. A sensitivity analysis would then be undertaken. This would re-do the CBA analysis to take in the following possibilities, taking each in isolation:

- Electricity outputs might be higher or lower than engineers are predicting
- The price of electricity might be rising or falling over time
- People may “get used” to the appearance of either windfarm, so the dis-amenity costs might be falling over time, perhaps to zero
- The government might specify the use of a carbon price which is rising over time – this would increase the value of avoided emissions.
- The windfarms may generate output for more than 15 years
- A different discount rate should be tried, to see how sensitive the NPV is to the choice of discount rate.

6 Lessons and Recommendations for Sweden from the Scottish Wind Energy Experience

The preceding chapters have described a framework for assessing costs and benefits of renewable energy, reviewed Scottish experience with renewable energy, and also summarised global work on externalities. In this final chapter, we offer a series of suggested "lessons" which Swedish policymakers and regulators might learn from this. We categorise these into lessons relating to costs, and lessons relating to benefits.

Lessons relating to costs

1. The level of subsidy needed to support the deployment of wind turbines is decreasing as both global and domestic experience has increased and supply chains have matured. This is expected to continue in to the future, with lower subsidies being required in Scotland. It is recommended that Sweden expect the same as it progresses the deployment of wind farms and other renewable technologies. Subsidy programmes must be adaptable to the changing levels of required support so that excessive profits are not created and economic inefficiency or distortions occur.
2. A stable and predictable subsidy system must be put in place that will support investor confidence for long-term capital investment. The UK's Renewables Obligation programme will endure for 35 years, 2002 to 2037, but cannot be described as stable and predictable. Numerous changes to the programme occurred during its first 10 years of operation and a decision was made to no longer allow new entrants into the RO programme after 2017. Most of the changes were the result of lobbying efforts by investors who were seeking to

capture high economic rents from the programme by reducing market risk and creating guaranteed revenue flows. It is recommended that Sweden give measured consideration to adapting any subsidy programme in response to investor concerns over market risk and creating permanent excessively high subsidies.

3. Broad based multi-party political support can minimise the "political risk" of volatile renewable energy policy shifts. The change in government from Labour to Conservative combined with the economic downturn since 2008 has led to a re-evaluation and dramatic restructuring of the UK's renewables subsidy programme. A principle cause for this change has been a perception by the Conservative government that the costs of the subsidy were greater than the benefits in meeting clean energy goals and security. It is recommended that Sweden place a high priority on managing any subsidy programme through political consensus that considers the full lifetime of the programme.
4. Renewable energy subsidies have led to increased consumer electricity bills from the subsidy programme in Scotland and the UK. This will have different relative impacts on households according to their income, since poorer households typically spend a higher proportion of their total budget on fuel than richer households. Thus, incentivising renewable energy through mechanisms which ultimately are paid for by electricity consumers can have un-desirable distributional effects. It is recommended that Sweden consider complementary programmes to address adverse distributional effects if subsidised renewables start to adversely impact vulnerable households.
5. Related to this is the observation that in Scotland, increased electric bills have led to an increase in fuel poverty; although renewables have not had as large an impact as the general on-going increase in natural gas costs for power generation.
6. Many aspects of renewable electricity generate environmental costs: examples include hydro power impacts on fisheries, and wind farm impacts on landscapes and carbon storage on peat. Thorough and complete assessments of the environmental impacts from deploying renewable must be conducted in a transparent manner that engages all stakeholders in society and the impacted local communities

in particular. Scotland has experienced increasing challenges to wind farm deployments partially as a result of developers not engaging communities in a manner that creates a social license to operate. It is recommended that Sweden require a high standard of transparency and engagement with stakeholders by project developers to assure acceptable environmental impacts at the local and national level are attained.

7. There are many significant costs associated with wind farms projects that are outside individual project parameters, ie transmission lines, grid stability and balancing requirements due to intermittency. The government must be pro-active in how these costs must be paid and by whom, eg socialising costs across system users, government paying, private wind farm developer pays, etc. The UK government and industry regulators are still consulting on many of these issues which have led to significant delayed investment in projects across Scotland and the UK. It is recommended that Sweden have policies in fully in place on how these costs are to be addressed in order to facilitate project planning, evaluation, permitting and construction.

Lessons relating to benefits

8. Development of domestic wind energy has potential for significant rural economic development and national economic growth with the development of a domestic supply chain. The greater the domestic supply of services and materials, the greater the economic benefits which can be captured. The Scottish government has pursued an active role in promoting inward investment in the wind industry supply chain that has resulted in the equivalent of 11,000 full time jobs with several international companies locating facilities in country, and the creation or expansion of numerous small and medium sized enterprises. The Scottish government has also supported communities capturing a portion of the long term financial benefits from projects. There have been positive distributional effects on rural communities from wind farm developments. It is recommended that Sweden provide a supportive policy framework that facilitates domestic business firms participating in the expanding wind industry. It is also

recommended that support be given to communities negotiating agreements that bring significant long term financial benefits and development to the local population.

9. Government revenues can be increased from various taxes associated with renewables; corporate profit tax, business rates, employment taxes, sales tax or VAT, etc. However, this may be offset with a decline in tax revenues associated with non-renewables. Both Scotland and the UK governments have experienced an impact on revenues from the development of renewables by the creation and expansion of a new industrial sector that has been a net benefit to date. There have also been distributional impacts as projects have been deployed into rural areas and increase the local tax base as well as the national. It is recommended that Sweden allow local governments greater ability to capture revenues from such developments.
10. Community energy projects are less economically efficient investments than large commercial projects, but may provide significant direct and indirect social benefits. Scotland has demonstrated that significant financial and non-financial benefits can accrue to local communities from ownership of appropriately scaled projects. It is recommended that Sweden promote policies that support community owned renewable energy projects.
11. Community engagement in planning wind farm projects is vital to acquiring a social license to operate and minimising the conflict over development. Scotland has a strong commitment for community engagement and delivery of community benefits where renewable energy projects are deployed. This has demonstrated value in creating or increasing local acceptance of projects. It is recommended that Sweden require substantial community engagement as a way of decreasing conflict over developments.
12. Wind farms do impact the environment as noted above, and will be received both positively and negatively. Some people see them as a positive symbol of clean energy and kinetic art in the landscape, while others perceive them as having negative impacts that adversely change the landscape and the community. The Scottish Government and local councils have invested significant effort in attempting to balance the preferences of it population in regards to renewables so the

most adverse projects do not receive consent and the most beneficial projects are not denied. It is recommended that Sweden pursue a similar balancing of concerns.

13. Renewable energy also allows for a reduction in the externalities associated with non-renewable sources, such as particulate emissions from coal burning and carbon emissions from both coal and gas powered stations. Scotland has been able to reduce it carbon emissions by displacing fossil-fuelled electricity with power from wind farms. Even though Sweden has limited use of fossil fuels for electric power generation it is recommended that renewably generated power be required to displace fossil-fuelled power as a priority to capture the maximum amount of environmental benefits.
14. Cost-benefit analysis is a powerful technique for comparing the benefits and costs of renewable energy at both the individual project level and the national energy policy level. However, there are many uncertainties attached to future cost and benefit flows, which economists have limited techniques for dealing with.

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