Building a Sustainable Energy Future: Supply and Demand Options

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***Abstract*— Fossil fuel depletion and concerns over global climate change are increasing the demand for sustainable and clean solutions for electricity generation. In the coming years some of the most difficult engineering challenges in history will have to be faced if a future with sustainable energy is to be developed. In light of this challenge investments in human infrastructure are essential in particular for early stage students who represent the generation who will have to truly solve future energy needs. This paper discusses an initiative in Ireland to foster an interest in energy issues for undergraduate students. A report made by the students on sustainable energy issues in Ireland is discussed here. The students focussed on recommendations that can be achieved in the short to medium term thus in many cases the infrastructural changes needed are simply a change in thinking or operational approach. One of the key infrastructural issues that arose is the importance of spatial planning in all areas of energy demand and supply.**

***Index Terms*— Sustainability, power generation, energy, alternative energy sources, energy infrastructure.**

I. Introduction

ECONOMIC growth and increasing standards of living have led to a dramatic increase in electricity demand over the past decades resulting in a rapid depletion of fossil fuel resources and growing concerns over global emissions. As a result, policy makers are now faced with the challenge of meeting future electricity demand growth in a manner which is both sustainable and clean.

In the coming years some of the most difficult engineering challenges in history will have to be faced if a future with sustainable energy is to be developed. Education and research will be fundamental tools if a sustainable future is to be secured. Despite the media attention devoted to issues surrounding fossil fuel depletion and renewable generation, one of the major challenges facing the energy industry is a lack of young qualified professionals in the area. As discussed in [1], investment in energy research and development in the US has declined steadily since the mid-1990s, despite calls for an enhancement of the nation's capacity for innovation. With respect to Ireland, numbers studying engineering and technology represent just over 13% of those entering Irish Universities and this figure is falling and in particular students are simply not choosing electrical and electronic engineering disciplines [2]. If future energy challenges are to be addressed, the human infrastructure is essential.

In a bid to foster interest in energy issues, the Irish Government launched an energy research scheme in January 2007 to provide funding for researchers in energy. This scheme, known as the Charles Parsons Energy Research Awards (CPERA), included funding for postgraduate research as well as undergraduate summer students. Under the CPERA the Electricity Research Centre at University College Dublin took on 10 undergraduate students for three months from June to September 2007. These undergraduate students named their group "Energy Needs Ireland" (ENI) and were made up of 2 first year students, 2 second years, 4 third years and 2 final year students across electrical and mechanical engineering disciplines. The ENI students were set the challenge of "determining how Ireland will meet its future energy demand in a manner that is sustainable, competitive and offers security of supply". This project was designed to fulfill three goals: firstly to create an interest in energy issues for students in an effort to build on human capacity in energy research and to create capacity for the electricity industry in the future; secondly to examine the challenge of securing a sustainable energy supply with 'fresh eyes' in an unbiased manner; and thirdly, to provoke debate and action on issues of sustainability raised and on the recommendations made by the students.

The final report produced by the ENI students was met with a resounding positive response from policy makers, industry and academia alike. The Minister for Communications, Energy and Natural Resources personally wrote the foreword for the final report and he launched the document officially in September 2007. The offshoot of the project has been unprecedented with the students being requested to present at conferences, at other Universities around the country, and to secondary school students [3].

Fig. 1. Minister Eamon Ryan launching the ENI final report; and the final report

This paper has a dual premise: firstly it focusses on the

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importance of building human infrastructure in the energy area; and secondly it discusses the recommendations for a sustainable energy future as investigated by the ENI group of young engineers with specific reference to the infrastructural challenges that would need to be overcome. The ENI report focussed on recommendations that can be achieved in the short to medium term thus in many cases the infrastructural changes needed are simply a change in thinking or operational approach. The following section details the project the students were set and their recommendations for securing a sustainable energy supply for Ireland. Section III discusses the lessons that were learnt by running the ENI project and highlights the major theme of spatial planning that was emphasised in the work and which has direct implications for all sustainable energy solutions. The conclusions are presented in Section IV

II. The Project and the Recommendations

At the beginning of June 2007 the ten young engineering students were given the challenge of determining how Ireland should sustainably meet its future energy needs. The students offered a uniquely unbiased outlook as summarised in the document:

"We have tried to be visionary in this document. We are not sensitive to anyone's point of view; we've just tried our best to find sustainable solutions. We care not for the concerns of politicians or vested-interests. We have no wish to perpetuate the many bad habits of the past. The time for change is now. We believe that easy solutions exist, and we outline many in this document. We believe these solutions can and must work. In many cases, all that is needed is a change of habit" [3].

The project was divided into three tranches: electricity generation; building efficiency and heat; and transport. For the purposes of this paper, the focus will be on the recommendations and infrastructures which will provide either a reduction in electricity demand or sustainable electrical energy provision.

A. Electricity

Currently over 93% of Ireland's electricity is generated from fossil fuels with renewables representing 4.5% of the electricity generation fuel mix. Of these renewables, wind and hydro are the dominant sources contributing 1.2% and 2.7% respectively [4]. Natural gas is the most commonly employed fuel, making up over 45% of electricity generation. Ireland has a large natural peat resource and peat generation represents 8.9% of installed generation. These peat units are highly carbon intensive producing approximately 1.13 tonnes of CO_2 per MWh, compared to approximately 0.35 tonnes/MWh for a CCGT. Current predictions for future electricity generation by fuel are shown in Figure 3 below

Figure 3 illustrates Ireland's continuing dependence on fossil fuels in power generation. In 2005, 25 TWh was generated from fossil fuel sources, even under optimistic forecasts, this figure will increase to 26.5 TWh in 2020. Growth in renewables is only covering growth in demand rather than

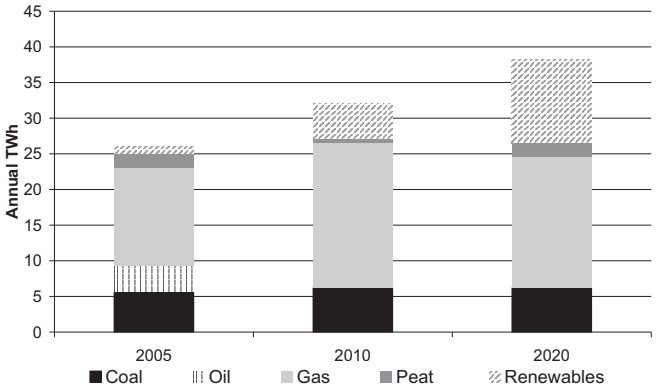

Fig. 2. Electricity generation by fuel [5]

displacing fossil sources, essentially Ireland is 'running to stand still'. ENI's vision is for Ireland's electricity to possess three characteristics - to be sustainable, secure and less carbon-intensive. ENI's recommendations to achieve this include:

- **A move away from using electricity in devices that solely produce heat**. Electric cookers, kettles, hot water and space heaters convert electrical energy into heat energy. Due to the considerable conversion inefficiencies inherent in generating electricity, a unit of electrical energy contains only about 40% of the heat energy that was used to make it. Accordingly, to get the same heat from burning a litre of gas at the point of use, two and a half time as much fuel would be required in a power station. *Infrastructures* that would be needed to support this recommendation would include shifts from electric to gas cookers, from immersion heaters to gas/biomass boilers and even from electric kettles to gas-fired modes of boiling water. This may require the expansion of the gas network infrastructure. While these changes could be phased in over a number of years it is vital for the Irish Government to make the public aware of the choices that are available to them and the importance of electricity conservation.
- **Maintain Ireland as an attractive place to invest in wind generation**. Ireland has an enviable wind resource and Irish wind farms have load factors in excess of 35%. The recent all island renewable grid study [6] has shown that wind generation could feasibly represent above 30% of electricity generation by 2020. In order to achieve these levels of wind energy penetration certain *infrastructural* changes will be required. A more flexible generation plant mix will be required which could include increased interconnection and demand side management. There is currently a worldwide shortage of wind turbines as demand has increased significantly over the past five years. With many European countries scrambling to build wind farms to meet renewable targets and the burgeoning Chinese economy consuming engineering materials apace, the capital cost of wind turbines are steadily increasing. If wind developers are to continue to invest in Ireland it may be necessary to increase capital support schemes for wind generation in Ireland. In addition, ENI found

that spatial planning issues were key with regard to wind generation. If Ireland continues with its legacy of one-off low density rural housing it is likely that the availability of suitable wind farm sites will reduce significantly. Other *infrastructural* changes that would facilitate the growth in wind generation include investments in grid infrastructure, communications and software capabilities, rural road network etc. As a caveat, ENI recommends that micro-generation from wind turbines should not be pursued given the economies of scale associated with larger wind turbines.

- **Demand side smart metering**. Smart metering can offer a lot more than just time specific tariffs and savings on meter-readings. Sophisticated smart meters can operate as integrated building management systems, constantly communicating with the grid and with all devices within the premises. Smart meters can allow many revolutionary changes in how a power system deals with demand. For example, demand shedding can prioritised and domestic tariffs can be adjusted depending on the required level of reliability, loads can be scheduled, tariffs could be revolutionised with sophisticated time and location specific pricing. The potentials are endless. While smart metering can be implemented immediately there are a number of *infrastructural* issues which must be addressed to maximise the potential of any such scheme. Flexibility is imperative and should be incorporated from the start, proprietary standards and protocols should be avoided. Given that smart meters, once installed in homes and businesses, may remain operational for well over twenty years it would be short sighted to lock into an inflexible, supplier specific solution. The IT infrastructure supporting smart meters should be open and flexible and allow for upgrading to more sophisticated meters in the future.
- **Increased interconnection**. Increased interconnection is an *infrastructural* recommendation which would have significant benefits for an island system such as Ireland. Increased interconnection would significantly improve security of supply, increase competition, and could defer the need for investment in generation capacity. In addition, an increase in interconnection would significantly increase the flexibility of the electricity system and therefore the potential for large penetrations of intermittent generation sources such as wind.
- **Phase out the use of peat in electricity generation**. Peat as a fuel source in electricity generation is expensive and highly carbon intensive. Despite this, it is currently financially supported by the Irish Government through a tariff on consumer electricity bills. Peat generation produces almost three times as much carbon dioxide as a CCGT as such it appears paradoxical to provide a subsidy to the most carbon-intensive fuel in the plant mix and is entirely at odds with climate change targets. The moth-balling of the peat stations would require little *infrastructural* change and in fact, these same stations could be considered as options for biomass generation with minimal alterations.

B. Building Efficiency and Heating

Energy use in buildings takes the form of heating, cooling, hot water heating, lighting, and electrical appliances. Over the past 15 years, there has been a 230% growth in the demand for domestic electricity, with the majority of this demand being used for lighting, appliances and communication equipment. Approximately 20% of Ireland's final energy consumption is used to provide water and space heating with electricity making up over 25% of this energy [5].

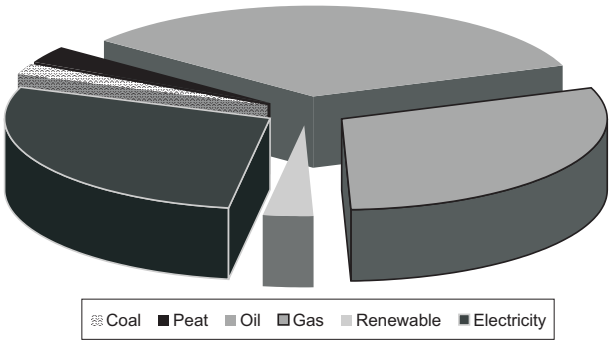

Fig. 3. Breakdown of energy use in Irish buildings [5]

At present, much of Ireland's heating energy is wasted through substandard insulation and poor building design. ENI's vision for the building and heating sector is to develop solutions which would allow Ireland to source its energy in a sustainable and affordable manner while maintaining a competitive economy with a high standard of living [3]. ENI's recommendations to achieve this include:

- **An all-out ban on the sale of incandescent light bulbs**. Lighting is one of the largest consumers of electricity in the typical home and incandescent bulbs are the most common bulbs used. This is despite the fact that incandescent bulbs have only a maximum efficiency of 10% with over 90% of their energy converted to heat energy [7]. In fact, incandescent bulbs should be considered as heating appliances with lighting simply a byproduct. By switching to compact fluorescent lamps (CFLs), consumers could save up to 70% of their lighting energy needs. *Infrastructures* required to implement this ban are minimal with the main deterrent for CFLs being their price, which is on average 3-10 times higher than incandescent bulbs, however, the extended lifespan of CFLs more than compensates for the initial cost. In fact, the Australian and Canadian Governments will ban incandescent bulbs from 2010 and 2012 respectively.
- **Incentives for District Heating Schemes**. District heating is an efficient method of heating densely populated areas through a central heat source, with the heat being distributed to the consumer via a piping system. District heating does not require dedicated heat plants; it can harness the waste heat that is being released from industry and power plants or utilise renewable sources such as geothermal, solar and natural resources, or even by waste incinerators. *Infrastructures* required to pursue district heating schemes in Ireland would include a move away

from the development of power plants in isolated areas to urban areas and the installation of piping systems for heat transportation. With regard to the first point, the Irish government has a target of increasing CHP production to 400MW by 2010 and 800MW by 2020 which would be ideal for developing district heating schemes. In addition, Dublin city has a number of power stations and a proposed incinerator located near urban areas which could be utilised as part of a district heating scheme. The implementation of a district heating scheme could significantly improve the efficiencies of electric power generation.

- **Incentives for solar water heaters**. Active solar appliances directly heat water to provide central heating and hot water. The typical opposition to solar heating is the high initial capital cost, and it is often perceived that sunshine hours in Ireland aren't high enough for the panels to provide economical and adequate heating. However, in reality direct sunlight isn't required for panels to heat water and the payback period can be as short as 2.5 - 3 years thus it is an ideal solution for heating the majority of Ireland's homes and businesses. The active solar industry in Ireland is small and lacks the *infrastructure* of a mature business. If active solar is to be pursued the industry must be able to respond to consumer demand and provide product support, customer service, operator training etc. In addition, public awareness of the benefits of domestic conservation applications such as solar water heaters is crucial.

C. Transport

The dual challenges of climate change and uncertain (yet rising) oil prices have focused western attention on alternatives to petrol, diesel and the internal combustion engine. Transport is the largest, fastest growing and most fossil fuel dependent sector in Ireland yet little is being done to curb demand. ENI's vision is for Ireland to use dramatically less energy in transport, in particular with respect to electrical energy, ENI recommend the following:

- **Electric Vehicles**. Battery electric vehicles in Ireland are likely to achieve a well-to-wheels efficiency of about 31% (taking account of losses during charging and discharging and the average efficiency of electricity generation) [3]. Internal combustion engines typically suffer from very low efficiencies. On standardised driving cycles they generally have a powertrain efficiency of 20% when transmission and frictional loses are included [8]. Since petrol and diesel have always been inexpensive on an energy basis this hasn't been a particular problem, however, this is now changing. From an *infrastructural* perspective the impact of introducing a large number of electric vehicles on to the electric grid would need to be examined in detail. Modifications would be needed to the local grid infrastructure especially if electric vehicles were used as short term electricity storage requiring two way energy flows.

III. Lessons Learnt

The ENI initiative was highly successful and the students raised numerous interesting and progressive issues for debate. This section introduces the issue of spatial planning which was found to be a key infrastructural issue which had significant impact in all areas of energy use. Also discussed, in relation to building human infrastructure, are the academic and educational implications of ENI initiative and the need for public awareness.

A. Spatial Planning

Throughout the course of their studies, the ENI students came to the conclusion that energy usage is significantly governed by the distribution of the population, which is particularly sporadic in Ireland. Ireland's trend of favouring low density housing has resulted in the consumption of excessive energy in particular during the housing boom in the nineties. Ireland's poor spatial planning has given rise to Ireland having three times the EU average length of power line resulting in over investment in cabling and increased losses. In addition, one-off rural housing could potentially increase the frequency of local opposition for wind farm development and reduce the number of viable sites. Smart metering schemes are much easier to trial and implement in urban areas with high population density. The installation and maintenance costs of a roll out of smart metering are increased with a highly dispersed population.

Well planned communities could also benefit from district heating schemes. Combined heat and power stations could provide heat for district heating schemes in addition to electricity in an efficient manner. Obviously, spatial planning is particularly relevant in the transport sector. The farther people are situated from where they work, the more fuel they will require. In Ireland, the average commuting distance to the workplace is 21km with 70% travelling in private vehicles [9]. While a move towards electric vehicles could potentially provide a sustainable option for the transport sector, the feasibility of using these vehicles for longer commutes is uncertain.

The idea of spatial planning is one of the fundamental issues challenging Ireland to achieve a sustainable energy future. While mistakes have been made in the past it is hoped that lessons will have been learnt and a far-sighted, innovative national spatial plan will be developed.

B. Building Human Capacity

One of the goals of the ENI project was to stimulate an interest in the energy sector among students. These students represent the generation who will have to truly solve our energy needs. These students acted as a team in an almost independent manner relying mainly on their own initiative and talents. Over the summer they made huge progress and ultimately produced a concise report [3], the launch of which was opened by Minister Eamon Ryan, Minister for Energy, on September 24th. Their report and presentation have been received extremely well by all members of the energy sector

- indeed, the students have made a valuable contribution to the energy debate. In addition, the success of the project has been validated by many key figures in the energy industry in Ireland today.

The success of the project in terms of energy research has also been shown with the only two final year ENI students now enrolled for research postgraduate degrees in the Electricity Research Centre. In addition, the only two first year students were in general engineering and have now elected to pursue the electrical and electronic field for their final degrees.

The Electricity Research Centre's longer term plan, involving a major iteration of the concept for next summer and beyond, is likely to include students from secondary school level (aged 14 - 17). This type of project is fundamentally an outreach one, dedicated to the promotion of science and engineering.

If advances in sustainable energy technology and infrastructure are to be achieved the fostering of interest in engineering and science is essential.

C. Public Awareness and Conservation

Public attitude and awareness is a major component in electricity conservation. A 'culture of conservation' needs to be developed in Ireland with the public being made consciously aware of the link between wasting electricity and wasting fossil fuels and needless carbon emissions. If you have a leaking bucket you don't continue to power in water relentlessly, you first fix the hole. The same analogy can be applied to the current energy situation in Ireland. The first step towards improving the situation is obviously to block the hole, that is, Ireland must minimise its energy requirements before attempting to meet them sensibly.

Many of the recommendations set out here require little infrastructural change per se but require a change of habit by consumers. The public need to be aware of the best technologies they can use in their homes, the most efficient way to travel and how they can reduce their personal energy usage and hence carbon footprint. Hard hitting media campaigns which show real and straightforward conservation solutions should be supported by Government. In addition, measures aimed at teaching young children the importance of energy conservation should also be encouraged. A further campaign aimed at dispelling some of the myths surrounding renewable generation developments could go a long way towards helping curb public opposition to renewable energy deployment.

IV. Conclusions

The importance of human infrastructure is critical to the development of a sustainable energy future. This paper discussed a summer project set for undergraduate students on solving Ireland's energy future. This project aimed to build energy knowledge and interest among the generation which will be tasked with solving Ireland's future energy needs. The initiative was highly successful and attracted significant attention both by industry and academia.

The recommendations made by the students were discussed here with respect to the infrastructural changes required to achieve them. It was found that one of the key drivers of Ireland's energy solution was a coherent spacial planning strategy. Ireland's legacy of low density rural housing has resulted in excessive energy consumption in the areas of electricity, building and transport energy.

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