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Expanded Emissions and Energy Targeting: A Further Application of CO_2 Emissions Pinch Analysis (CEPA) to the Irish Electricity Generation Sector

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This paper presents the methodologies and data sources that are used for a renewable energy source-electricity/renewables' minimisation study in the Irish electricity generation sector over the period 2008-2020. As of the first quarter of 2009, the energy and emissions data for the years upto and including 2007 have been reported by Ireland's relevant bodies. Hence, the projected energy and emissions data for 2008 onwards is of interest in this paper. The main reason for this minimisation of renewables is the sector's vulnerability to their disadvantages in the coming years, especially the intermittency and variability of the ever-dominating wind generated electricity. The CO_2 Emissions Pinch Analysis (CEPA) methodology is able to determine the optimal/absolute minimum amount of renewables that should be used in an energy resource mix. This mix has its total emissions satisfying a given Kyoto limit. A fifth adaptation to the basic CEPA methodology is presented here and it is called the TGEC adaptation. It allows for the very useful comparison of the projected optimal amounts of renewables to the incrementally determined targets on the amounts of renewables that Ireland is legally obliged to achieve in each of the coming years (starting at 2008). These future interpolated targets are determined from the government and European Union end-of-period targets that are laid out in the associated policy documents.
Keywords: Renewable energy source-electricity/renewables, [projected] energy and emissions data, renewables' disadvantages, CEPA methodology, optimal/absolute minimum, fifth adaptation, projected optimal amounts, targets, policy.

1. Introduction

The theme of our research work is Ireland's electricity generation sector and the contribution that renewable energy source-electricity (or, renewables) can make to it. The sector's energy growth, emissions growth and policy framework are now considered in order to serve as an introduction to the sector's current standing.

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1.1 Sector's energy growth

The sector has undergone massive growth in its total primary energy requirement (TPER); in 2007 it had risen by approximately 63.20% since 1990. Over half of this TPER in 2007 came from natural gas, 30% from coal and peat combined and a rapidly rising five per cent from renewables, of which these are now mainly wind generated electricity (WGE). Oil and net imported electricity (originating in the United Kingdom) also contributed to the sector's actual energy (i.e. TPER) resource mix in 2007. There has, however, been a noted decoupling of this TPER growth from Ireland's economic (i.e. gross domestic product) growth over the same period. This is because Ireland's economy grew by almost 190.40% between 1990 and 2007. This was over three times higher than the corresponding TPER growth (Sustainable Energy Ireland, 2008).

1.2 Sector's emissions growth

The sector's greenhouse gas (GHG) emissions have increased by approximately 27.38% between 1990 and 2007. This almost mirrored the increase of approximately 24.96% in Ireland's total GHG emissions over the same period. Under the terms of the European Union (EU) burden-sharing agreement on the Kyoto Protocol, Ireland is only allowed to increase its total GHG emissions by 13% (compared to the 1990 baseline level) during each of the years 2008-2012. The sector's contribution to the total GHG emissions was around 21.55% in 2007 (compared to 21.14% in 1990) so it has a very significant part to play in Ireland's future commitments under the Kyoto Protocol (Environmental Protection Agency, 2009a).

1.3 Sector's policy framework

In addition to the Kyoto protocol, some of the most important national and international policies that apply to the sector are as follows:

(i) EU Directive on Renewables (2001) – This stated Ireland's obligation to produce 13.2% of its total gross electricity consumption (TGEC) from renewables in 2010 (Sustainable Energy Ireland, 2008).

(ii) Government White Paper on Energy (2007) – This increased the above 13.2% target to 15% and the target for 2020 was set at 33%, which itself has recently been increased to 40% (Sustainable Energy Ireland, 2008).
[Note: Renewables represented approximately 9.43% of TGEC in 2007]

(iii) EU Directive on Renewables (2008) – This expressed Ireland's obligation to produce 16% of its total final consumption (TFC) within the electricity, transport and heating sectors from renewables in 2010 (Sustainable Energy Ireland, 2008).
[Note: Renewables represented approximately 3.57% of TFC within the electricity, transport and heating sectors in 2007]

(iv) EirGrid's €4 billion (over 2008-2025) and ESB's €22 billion (over 2008-2020) investment plans – These will reinforce and strengthen the sector's infrastructure for handling the projected increases in renewables over the coming years, which are obligatory under (a)-to-(c) above (EirGrid, 2008; Electricity Supply Board, 2008).

(v) EU Commission's Draft Decision on Post-Kyoto Emissions Targets (2008) – This presented Ireland's obligation to reduce its total GHG emissions in 2020 by an indicative 20% below the new 2005 baseline level (or 1.49% above the Kyoto 1990 baseline level). This will increase to 30% (or 11.20% below, respectively) if a new post-Kyoto global climate agreement is reached in the near future (Environmental Protection Agency, 2009a, b).

1.4 Aims and objectives

In light of the energy, emissions and policy information presented, Ireland's electricity generation sector has experienced a rapid growth in renewables over the last number of years. This is projected to increase in the coming years and WGE will be the main renewable that drives this growth (Sustainable Energy Ireland, 2008). This is desirable in helping to displace the future GHG emissions from fossil fuel power plants but this may leave the sector susceptible to the availability, intermittency, unpredictability and variability of WGE. These are just a few of the disadvantages of WGE. Furthermore, the current weakly reinforced nature of the sector's grid infrastructure means that, at present, the sector is far from ideally placed to be handling the significant increases of renewables that are planned in the future. Finally, the sector's current low degree of interconnection with the much larger United Kingdom grid leaves it precariously vulnerable, going forward, to WGE's variability.

A methodology for the minimisation of renewables (of which this is mainly WGE) is justified by these reasons. Such a methodology can be applied to the projected 2008-2020 data for the sector's TGEC-by-resource and GHG emissions, respectively (Sustainable Energy Ireland, 2008; Environmental Protection Agency, 2009b). Comparison of the resulting data from the methodology can be made with the TGEC-by-renewables targets (i.e. (a)-to-(c) above) and the GHG emissions targets (i.e. (e) above), respectively. Both of these types of targets are obligatory for the sector over the period 2008-2020.

2. Methodology

The recently developed pinch approach for carbon-constrained planning in the energy sector is our chosen methodology (Tan and Foo, 2007). We refer to this as the CO_2 emission pinch analysis (CEPA) methodology (Crilly and Zhelev, 2008a). The fifth new adaptation to the original form of the CEPA methodology is now presented in preparation for our future results. It deals with the expanded emissions and energy targeting of future years' projections in the megatonnes of $CO_{2(equivalent)}$ (Mt $CO_{2(e)}$)-versus-terajoules of TGEC (TJ_{TGEC}) co-ordinate system.

2.1 CEPA methodology for renewables' minimisation

The CEPA methodology is linear programming-based and it involved the graphical plotting of an energy demand (i.e. the total actual energy demand (TAED)) and an equal energy resource (i.e. the total actual energy resource (TAER)). This took place in the mass of CO_2-versus-energy co-ordinate system (Tan and Foo, 2007). The slopes of the TAED/TAER line segments in this system had units of Mt $CO_{2(e)}$ TJ^{-1}, which were the same units as the emission factors (EFs) of a region's demand and resources. The presented procedure of energy sector planning with CO_2 emission constraints involved an objective function that minimised/optimised the amount of clean energy resources with assumed zero EFs. The resource-by-resource breakdown of the TAER was called the actual energy resource mix in our terminology, or AERM for short. The total emissions (i.e. the total actual emissions (TAE)) produced by the AERM was less than the Kyoto limit for the TAED. The resource-by-resource breakdown of the TAE was called the actual emissions mix, or AEM for short. The optimisation procedure determined the optimal (i.e. absolute minimum) amount of clean resources/renewables. This amount was greater than their amount in the AERM. This meant that the other resources(s) with the highest EF(s) were to be rejected because they were otherwise in excess. The resulting total optimal energy demand (i.e. TOED) and the total optimal energy resource (i.e. TOER) were the same as the original TAED and the TAER, respectively. The optimal energy resource mix (i.e. OERM) and the optimal emissions mix (i.e. OEM) therefore contained the optimal contribution from renewables. The total emissions (i.e. the total optimal emissions (TOE)) produced by the OERM were now equal to the same Kyoto limit so this necessary constraint was satisfied by the optimisation procedure.

Four adaptations to this basic CEPA methodology were suggested in order for it to be applied to the Irish electricity generation sector (Crilly and Zhelev, 2007). The first adaptation briefly dealt with forecasting while the second was called the time pinch/dynamics adaptation. The sector's data (both past/historical and future/projected) was used as a case study for each of these adaptations (Crilly and Zhelev, 2008a). The projected data was the most up-to-date available at the time of publication in late 2007. The third adaptation (i.e. division-of-renewables) and the fourth adaptation (i.e. disturbances-and-pinch jumps) were presented and applied to the sector's statistics for 2005 and 2006 (Crilly and Zhelev 2008b).

2.2 Reasons for fifth adaptation to CEPA

The Mt $CO_{2(e)}$-versus-TJ_{TPER} co-ordinate system was common to the first, third and fourth adaptations. The optimal amounts of renewables that were calculated were therefore expressed in TJ_{TPER}. This unit was not the preferable form for the comparison of these optimal amounts of renewables (together with their actual amounts) with the aforementioned TGEC targets. Furthermore, there is a certain amount of ambiguity involved in the TPER amount for renewables because this amount can also be expressed in terms of a total primary energy equivalent (TPEE) amount for renewables. This would also have units of terajoules (i.e. TJ_{TPEE}) and while it is common in some energy reporting procedures, it is far from being consistent (International Energy Agency, 2008).

The fifth adaptation to the basic CEPA methodology involves calculating the projected optimal amounts of renewables in terms of TJ_{TGEC}. This is achieved by changing to a Mt $CO_{2(e)}$-versus-TJ_{TGEC} co-ordinate system for use with the future/projected AERMs and AEMs. In this way, the optimal TJ_{TGEC} amounts of renewables can be directly compared with the interpolated (linearly interpolated, or otherwise) EU and government TGEC targets for renewables. In addition, the ambiguity of TJ_{TPEE} is avoided using the TJ_{TGEC} approach. The fifth adaptation is called the TGEC adaptation.

3. Pre-requisite data and tools

The following is the summary of the data sources and calculation procedures that are intended to be used in the renewables' minimisation study for the sector:

(i) Sustainable Energy Ireland (2008) listed the sector's projected TGEC-by-resource data over the period from 2008 to 2020. This data was projected under the most relevant White Paper scenario of the sector's energy forecasts.

(ii) Environmental Protection Agency (2009b) produced the sector's projected GHG emissions over the period from 2008 to 2020. This data was projected using the most relevant Economic Shock analysis, which was applied to the With Additional Measures scenario. This scenario was in turn linked to the most relevant White Paper scenario above.

(iii) Sustainable Energy Ireland (2008) tabulated the sector's EFs for each of its four fossil fuels. These were valid only during 2007 so it was assumed that the same EFs would also apply over the period from 2008 to 2020. The sector's EFs for each of its renewables were assumed to be zero for each of the past/historical years and for each of the future/projected years. The Scottish Government Publications (2006) gave the EF for the sector's net imported electricity (from the UK via Northern Ireland) during 2006. It was assumed that the same EF would also apply over the period from 2008 to 2020.

(iv) International Energy Agency (2008) partially revealed the sector's past TGEC-by-resource data over the period from 1990 to 2006. This can be used in conjunction with the sector's past TGEC data over the period 1990-2006 (Sustainable Energy Ireland, 2006, 2008). The result will be the fully determined TGEC-by-resource data for the sector over the past period 1990 to 2006. This can then be used to determine the efficiency of electricity generation over this same period. An extrapolated trend of this would also apply over the 2008-2020 period.

4. Results, discussion and conclusions

The determination of the sector's projected optimal amounts of renewables (in terms of TJ_{TGEC}) over the period 2008-2020 is still under investigation. It is hoped to present our results in either oral or poster form at the PRES '09 conference. The comparison of these to the linearly interpolated EU and government TGEC targets for renewables over this same period will show the strength and usefulness of the fifth adaptation to the basic CEPA methodology.

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References

Crilly, D. and Zhelev T., 2007, Current trends in emissions targeting and planning, Proceedings of the 10th conference on process integration, modelling and optimisation for energy saving and pollution reduction (PRES '07), Chemical Engineering Transactions, vol. 1, Ed. Klemeš J., 91-97.

Crilly, D. and Zhelev T., 2008a, Emissions targeting and planning: An application of CO_2 emissions pinch analysis (CEPA) to the Irish electricity generation sector, Energy 33, 1498-1507.

Crilly, D. and Zhelev T., 2008b, Further trends in emissions targeting and planning – an application of CO_2 Emissions Pinch Analysis (CEPA) to the Irish electricity generation sector, Proceedings of the 18th international congress of chemical and process engineering (CHISA 2008) – Summaries 4: PRES 2008 and Systems Engineering, vol. 4, Ed. Novosad, J., 1214-1215.

EirGrid, 2008, Grid25 – A Strategy for the Development of Ireland's Electricity Grid for a Sustainable and Competitive Future. EirGrid, Dublin.

Electricity Supply Board, 2008, ESB announces €22billion spend in renewables future – ESB unveils strategic framework to 2020. Electricity Supply Board, Dublin.

Environmental Protection Agency, 2008, Ireland's National Allocation Plan for Emission Trading 2008-2012. Environmental Protection Agency, Wexford.

Environmental Protection Agency, 2009a, Ireland's Greenhouse Gas Emissions in 2007. Environmental Protection Agency, Wexford.

Environmental Protection Agency, 2009b, Ireland's Greenhouse Gas Emission Projections 2008-2020. Environmental Protection Agency, Wexford.

International Energy Agency, 2008, Electricity Information 2008 (with 2007 data). International Energy Agency, Paris.

Sustainable Energy Ireland, 2006, Energy statistics data. Sustainable Energy Ireland, Dublin.

Sustainable Energy Ireland, 2008, Energy in Ireland 1990-2007: 2008 Report. Sustainable Energy Ireland, Dublin.

Tan, R.R. and Foo, D.C.Y., 2007, Pinch analysis approach to carbon-constrained energy sector planning, Energy 32, 1422-1429.

The Scottish Government Publications, 2006, Scottish energy study: volume 1: energy in Scotland: supply and demand – Appendix 7 CO_2 allocation approaches for electricity. The Scottish Government Publications, Edinburgh.