CHEMICAL ENGINEERING TRANSACTIONS, Volume 12, 2007
Edited by Jiri Klemeš
 ISBN 88-901915-4-6

Current Trends In Emissions Targeting And Planning

Damien Crilly, Toshko Zhelev
Charles Parsons' Initiative on Energy and Sustainable Environment
University of Limerick, National Technological Park, Plassey, Co. Limerick, Ireland

This paper outlines the guideline planning of the Irish electrical generation sector. The main two additions to the analysis are proposed as both the forecasting element and the account for the dynamic nature of the supply-demand infrastructure. The determination of an optimal fuel mix, which results from CO_2 emissions pinch analysis, for the Irish energy sector will look to give guidelines towards fulfilling Ireland's Kyoto targets in this sector, as well as yielding an approach for the other sectors to follow.

1. Introduction

1.1 International and Irish background to caps/limits/quotas/targets on CO_2 emissions

According to the terms of the latest derivative (or accord) of the Kyoto Protocol (1997) the E.U.-15 are obliged to an 8% reduction, below 1990 levels, in their annual greenhouse gas (GHG) emissions during the period 2008-2012. Under the EU's burden-sharing agreement, Ireland is permitted to increase its average 2008-2012 emissions by no more than 13%, thus translating to an equivalent CO_2 emissions target of approximately 63×10^6 tonnes per annum (Department of Marine, Communications and Natural Resources, 2006, p. 9) across all of the following sectors (Department of Environment, Heritage and Local Government, 2006, p. 1-5):

(A) (Electrical Generation) Energy (B) Transport
(C) Built Environment/Residential (D) Industry, Commercial and Services
(E) Agriculture (F) Waste (G) GHG Sinks (Opposite Of (i)-(vi))

A marked de-coupling/de-linking of economic growth from both energy consumption (i.e. total primary energy requirement (TPER)) and GHG emissions has occurred in Ireland during the period 1990-2004 (Department of Environment, Heritage and Local Government, 2006, p. 78). Furthermore, it is reported that it is (fossil) fuel-combustion processes (almost exclusively emit CO_2) that produced 65% of Ireland's GHGs in 2004, followed by the mainly CH_4-producing agriculture sector on 29%. Even with "existing policies and measures already implemented or expected to be implemented up to 2012" it is forecast that the country will have an average annual overshoot of approximately 7 million tonnes of equivalent CO_2 during the 2008-2012 time period. This paper aims to propose further steps to existing research so that the optimal (fossil) fuel mix for a region, which satisfies the regional energy demand, can be determined as an initial recommendation. Such a recommendation may primarily help to guide the planning of the Irish energy sector towards reaching its Kyoto goals, with lesser emphasis being placed on the analysis of the other sectors listed above i.e. each sector above can be assigned an equivalent CO_2 emissions limit.

1.2 Overview of the current status of CO_2 emissions planning

Tan and Foo (2006) present a novel application of pinch analysis for preliminary planning within the energy sector of a developed country. Developed countries are now subject to legally binding constraints on equivalent CO_2 emissions under the Kyoto protocol. Earlier works by Dhole and Linnhoff (1992) and Linnhoff and Dhole (1993) investigated emissions targeting through pinch analysis according to "total site analysis" i.e. a factory, comprising the summation of several industrial processes, whose material and energy needs are supplied by a central utility system. Tan and Foo (2006), however, waive this total site assumption by combining together different energy demand sectors. Their concept can be applied to either the regional CO_2 emissions resulting from only electrical energy (sector (A) above) consumption or the regional equivalent CO_2 emissions resulting from energy consumption in all of the sectors (B)-to-(F) introduced above. As previously stated, it is the former application that will be the main focus of this work. In their most realistic case study, the composite, region-by-region energy demand (or consumption) curve is classically constructed in the CO_2 emissions-versus-energy co-ordinate system. This kinked, cumulative energy demand curve is brought to touching point with the composite energy resource (or supply) curve. This procedure yields both the carbon emissions pinch point and the optimal target amounts (for each region) of each type of available energy resource. This analysis brings the regions, as a whole, within their respective Kyoto emission limits.

2. Adaptation Of CO_2 Emissions Planning To The Irish Context

2.1 Forecasting the future fuel mix of the energy sector

In its current form, CO_2 emissions pinch analysis is carried out on a region on the basis of estimating both the future energy demands and the future energy resources that operate within the region's pre-determined CO_2 emission limits. The optimal fuel mix is thereby determined but this may not be possible to implement in the future because of present capacity, policy and/or structural issues. An example of a capacity issue could be the current size, number and/or pressure rating of the region's installed natural gas pipelines that may not be able to handle any proposed increase in the amount of deliverable gas to meet the recommended fuel mix. Policy issues could represent either government policies and/or E.U. directives that prohibit a country becoming too dependent on certain fossil fuels, so as to minimise the effect of either international shortages or international price rises of the same. Finally, an example of a structural issue is the infrastructural problem of switching from, for instance, coal to natural gas in an existing power station. Past data for Irish electrical energy usage from 1990-2005 is readily available while the same is available for the Irish fuel mix of electrical generation during the same period. In our opinion, the prediction of the values of both of these variables into the future would allow for future CO_2

emissions to be predicted. The optimal fuel mix may also be determined based on the future predicted values of both energy usage and future CO_2 emissions, thereby allowance can be made for its planning into the future. Bearing this in mind, a reliable, accurate forecasting/prediction model is required.

Authors have reported on a variety of methods and models such as, but not restricted to, linear regression analysis, artificial neural networks, decision tree models, Grey prediction with rolling mechanism and Box-Jenkins methodology. Each of these models allow for the prediction of the future values of the chosen variables. The common feature of all methods/models is the requirement for the input of past values of the variables, which are called training points by Levis and Papageorgiou (2005). Their model represents one of the most reliable and preferred methodology encountered to date. They present support vector regression (SVR), which is optimisation-based, for the prediction of future customer demand e.g. the (variable) monthly sales of a chemical commodity. The predicted future values show a high degree ($\approx$ 95%) of accuracy compared to the benchmark of the actual future values. The authors note that SVR is essentially an "intelligent" analysis that can "learn" from both the past peaks and the past trends in the demand data in order to accurately "mimic" the future occurrences of both the peaks and the trends.

The aforementioned methodology best suits our forecasting goals. Any predicted values of the fuel mix, based on the past values of the fuel mix in the Irish electrical generation sector, may be compared with the (estimated) future value of the optimal fuel mix for the same. The optimal fuel mix results from the application of CO_2 emissions pinch on both the predicted values of Irish electrical energy usage and the future CO_2 emissions limits for the aforementioned sector.

Even the most reliable, accurate forecasting model cannot be totally robust to external disturbances affecting both the forecasted fuel mix and the forecasted energy usage, such as government/European Union directives and policies on reaching a certain penetration of energy efficient technologies by a certain date. Cars and domestic appliances are just two of the technologies coming under this heading regarding compulsory, definitive improvements to be made within certain dates. Ramírez et al. (2005) account for the energy efficiency changes over time in the Dutch food and tobacco industry by using an energy efficiency indicator (EEI) as follows:

$$EEI_{j,k} \cong \frac{E_{j,k}}{\sum m_{i,k} SEC_{i,j,0}} \tag{1}$$

In equation 1, subscripts i, j, k and 0 refer to the product, the fuel, the current year of analysis and the base year of reference respectively while E, m and SEC refer to the energy consumption, the mass of product and the mass-specific energy consumption respectively. They are confident that their future work will allow the transpose of their ideas to both other industries/sectors and other countries. We suggest using the SVR methodology to predict the future values of EEI for each fuel in the Irish energy sector. These values can be checked for compatibility with the previously forecasted values of both the fuel mix and the energy usage.

2.2 Accounting for the dynamic nature of energy demands and energy resources

Both the instantaneous power demands (prime example being daytime power demand-versus-nightime power demand) and power resources (prime example is wind power), are actually variables with respect to time – they have been integrated/summed over the timeline of a year in order to yield both the total energy demands and the total energy resources. These total amounts of energy, as introduced by Tan and Foo (2006), are not considering the time variable but our approach (i.e. that of the cumulative amounts of energy to date) will consider variations with respect to time. Our approach is to incorporate "time" pinch analysis (Wang and Smith (1995)) into CO_2 emission pinch so that definite account is taken of the intermittent/unsteady-state nature of both energy sources (supply) and energy sinks (consumption) throughout a given year.

Targeting in continuous (i.e. steady-state) CO_2 emissions pinch analysis involves finding all of the following:

(a) The absolute minimum amount of "others" (analogous with the minimum cold utility heat rate in continuous thermal pinch analysis).
(b) The "excess" amount of the energy resource with the highest emission factor (analogous with the minimum hot utility heat rate)
(c) The region of horizontal-projection of energy resource matched with energy demand (analogous with the maximum process-to-process recovery heat rate).

All targeting is performed for a zero value of the CO_2 emissions difference since the two composite curves touch one another at the CO_2 emissions pinch point. In short, the current form of CO_2 emissions pinch does not consider the dynamic nature of both the energy resources and the energy demands. We propose to forecast the changing of the CO_2 emissions pinch point over time because of ever-changing values of both power consumption and power supply.

2.3 Probing approximately (essentially) zero- and low-carbon energy resources

Tan and Foo (2006) perform the targeting phase of their CO_2 emissions pinch analysis such that only the absolute minimum amount of low-carbon energy resources is employed in the overall optimal fuel mix. They give the reasons that the whole collection of low-carbon energy resources are relatively expensive compared to fossil fuel energy resources and/or pose more of a security threat compared to fossil fuels and/or push the boundaries of public acceptability more than fossil fuels. Nuclear energy is a prime example of a member of the group of "others" that still satisfies each of the latter three criteria. Wind energy, however, may have satisfied both the 1st and 3rd criteria in the past but now it may be argued that only the visual sight (grouped into the 3rd criteria) of relatively inexpensive wind turbines is their sole drawback at the present time (Department of Environment, Heritage and Local Government, 2006, p. 34). A similar discussion on each of the remaining low-carbon energy

resources, from the point of view of environmental analyses (carbon footprint analysis, ecological footprint analysis and solar eMergy analysis), is left for future work.
Bearing all of this in mind, therefore, one of the proposed extensions to the body of knowledge of earlier concepts is to target for more than the absolute minimum amount of low-carbon energy resources, which results in the shifting of the composite energy resource curve further to the right on the horizontal axis. It also results in a new fuel mix with a lesser "excess" amount of the energy resource with the highest emission factor.

2.4 Forecasting, feasibility regions and Pinch jumps

Tan and Foo (2006) give exact values (in Joules) of the magnitudes of both the energy resources and the energy demands. We propose to place value ranges on the same in order to account for the effect of disturbances on the Irish energy sector. Such disturbances might include the short/medium-term weather effects on residential electrical energy use, the short/medium-term effects of rises in international fossil fuel prices on electrical energy usage and the medium/long-term effects of the continued increase in the price competitiveness of low-carbon energy resources in relation to traditional fossil fuel energy resources. The effects of these disturbances on the horizontal ordinate point (i.e. energy) result in changes to the vertical ordinate point (i.e. CO_2 emissions), thus there are resulting changes/shifts (or "jumps") to the CO_2 emissions pinch point. In our opinion, it would prove useful to be able to forecast these pinch jumps so that the feasible region (or range) of change, allowed to the energy ordinate in order for a certain pinch jump to occur, can be determined. If a classical problem table algorithm is constructed then any disturbances, from either the inlet value of CO_2 (on either an energy resource or an energy demand) or the inlet value of emission factor (on the same), may be propagated down through the various CO_2 emissions intervals. Zhelev et al. (1998) define all of the operability regions (pinch zones), the "pinch jumps" (i.e. the breakpoints in the resilience function) and the "pinch splitting", all of them related to the disturbances (including both inlet temperatures and inlet flow rates), in a thermal pinch problem. An operability assessment procedure is proposed and the method is made useful, not only to assess the system's operability within the specified expected changes (disturbances), but also to guide specific actions so as to return it into the operability zone. We propose an adaptation of the above procedure for the purposes of CO_2 emissions targeting and planning, which accounts for forecasted (predicted) disturbances.

2.5 Design for flexibility

Following on from the previous sub-section, it would be desirable to determine how to alleviate the knock-on effect(s) of any possible pinch jumps on the output CO_2 emissions of a region because otherwise the region's Kyoto limits may be breached by any rise in the output CO_2 emissions. If the structure of the Irish energy sector could somehow be adapted in order to compensate for the effect of pinch jumps, then the sector would ultimately be more flexible, more robust and more resilient to the initial disturbances to the sector. One possible way in which the Irish energy sector could be adapted would be to have a changeable fuel mix, which may not be near to the optimal fuel mix, for times when disturbances are affecting the CO_2 emissions pinch point. Ivanova et al. (2000) provide a methodology for the determination of the optimal locations in a heat exchanger network for the placement of bypasses. In times of disturbances to the inlet (hot or cold) temperatures and/or the inlet (hot or cold) heat capacity flow rates, bypasses are closed and the extra area within heat exchangers is employed in order to attempt to bring the network back to its equilibrium (i.e. design) point. In an analogous way, the effect of disturbances on the CO_2 emissions point could be negated by the ability to avoid/bypass certain constituent parts of the available fuel mix. The flexibility, robustness and resilience of the energy sector would therefore be increased.

3. Conclusions

In its current form, CO_2 emissions pinch analysis can be applied to the Irish electrical energy generation sector but it is our opinion that it must be adapted in order to account for the dynamic nature of all of changing energy usage, changing fuel mix, changing energy efficiency, changing governmental policy, changing E.U. policy and changing disturbances. We hope to be able to present examples of the proposed methodology adaptations in the extended version of this paper.

4. Acknowledgements

The team acknowledges the generous support of this research under the Embark Initiative of the Irish Research Council for Science, Engineering and Technology (IRCSET).

5. References

Dhole, V.R. and B. Linnhoff, 1992, Total site targets for fuel, co-generation, emissions, and cooling, Computers and Chemical Engineering 17, 101-109.

Environment, Heritage and Local Government, Department of, 2006, Ireland's Pathway To Kyoto Compliance – Review Of National Climate Change Strategy. Department Of Environment, Heritage and Local Government, Dublin.

Ivanova, E.A., N.S. Doichinov, I.V. Seikova and T.K. Zhelev, 2000, Structural Limitations In Optimal Bypass Placement In Heat Exchanger Networks, Hungarian Journal Of Industrial Chemistry 28, 167-173.

Levis, A.A. and L.G. Papageorgiou, 2005, Customer Demand Forecasting Via Support Vector Regression Analysis, Chemical Engineering Research and Design 83, 1009-1018.

Linnhoff, B. and V.R. Dhole, 1993, Targeting for CO_2 emissions for total sites, Chemical Engineering Technology 16, 252-259.

Marine, Communications and Natural Resources, Department of, 2006, Green Paper – Towards A Sustainable Energy Future For Ireland. Department of Marine, Communications and Natural Resources, Dublin.

Ramírez, C.A., K. Blok, M. Neelis and M. Patel, 2006, Adding apples and oranges: The monitoring of energy efficiency in the Dutch food industry, Energy Policy 34, 1720-1735.

Tan, R.R. and D.C. Foo, 2006, Pinch analysis approach to carbon-constrained energy sector planning, Energy, doi:10.1016/j.energy.2006.09.018.

Wang, Y.P. and R. Smith, 1995, Time Pinch Analysis, Chemical Engineering Research and Design 73, 905-914.

Zhelev, T.K. and R. Ridolfi, 2006, Energy recovery and environmental concerns addressed through emergy-pinch analysis, Energy 31, 2150-2162.

Zhelev, T.K., P.S. Varbanov and I. Seikova, 1998, HEN's Operability Analysis For Better Process Integrated Retrofit, Hungarian Journal Of Industrial Chemistry 26, 81-88.