CHEMICAL ENGINEERING TRANSACTIONS

VOL. 70, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Timothy G. Walmsley, Petar S. Varbanov, Rongxin Su, Jiří J. Klemeš

ISBN 978-88-95608-67-9; **ISSN** 2283-9216

DOI: 10.3303/CET1870004

Regional and National Greenhouse Gas Emissions Reduction Planning

Martin J. Atkins*, James R. Neale, Yi-Han Wu, Michael R.W. Walmsley

Energy Research Centre, School of Engineering, University of Waikato, Hamilton, New Zealand
martin.atkins@waikato.ac.nz

A Process Integration framework for estimating potential greenhouse gas emissions reductions from the industrial process heat sector is presented. It is important that Process Integration principles are applied to reduction measures to achieve the greatest benefits and avoid incorrect or sub-optimal integration (e.g. inappropriate placements of heat pumps). The basis of the framework develops process temperature demand profiles for industrial heating and cooling demand, allows targeting to be carried out, and provide a standard to assess emissions reduction measures against. In the method specific reduction measures are identified, which are integration appropriately and calculates the Marginal Abatement Cost (MAC) for each measure. MAC curves for individual processes or sectors can then be developed and compared, which are useful tools to assist in development of public policy tools that target emissions reduction from the industrial sector. Regional and national reduction potentials and estimates of costs can be estimated using the described framework. The formulation of good policy to encourage industry to transition to a low/zero carbon paradigm is essential for countries to meet their international emission reduction commitments. Preliminary results from an on-going study into New Zealand's industrial emissions is presented including MAC curves for two major processes, which show that a 6 % reduction in national industrial emissions can be made economically at current carbon costs from these two processes alone.

1. Introduction

Since the Paris Agreement, many countries are developing sector specific plans and policies to achieve their Greenhouse Gas (GHG) emissions reduction commitments. Public policy to incentivise GHG emissions reduction should be based on a sound evidence base to balance environmental and economic impacts and avoid negative or unintended consequences. For many countries, Renewable Electricity (RE) will play an important role in meeting commitments and many have set RE targets and started along this path (Atkins, 2016). There is typically an abundance of reliable electricity supply and demand data that forms a sound evidence base from which to develop RE targets, policy interventions and transition pathways. GHG emissions from industrial process heat (PH) are also significant and there are many cost effective abatement methods that can be implemented. National level industrial PH data is often incomplete with a high degree of uncertainty due to the decentralised nature of the supply and demand, and the difficulties with measurement and centralised data collection. Therefore, formulating effective public policy to expedite large-scale emissions reduction from the industrial PH sector is challenging due to an inadequate evidence base (Chapman et al., 2016). In this case the evidence base is comprised largely of the underlying energy use and GHG emissions data by industrial sector, company, location, etc.

The formulation of good policy to encourage industry to transition to a low/zero GHG emissions paradigm is essential (Kranzl et al., 2013) for countries to meet their international commitments, especially where there is limited scope for large scale decarbonisation of the electricity grid due to high levels of RE and/or nuclear, such as in New Zealand and France. Top-down analysis methods for national energy analysis also tend to dominate the inputs for policy making activities with limited contributions from engineers or large energy users (Jacobsen, 1998). Often policy interventions encourage the application of energy efficiency measures and new technologies and it is important that Process Integration (PI) principles are also followed to achieve the greatest benefits and to avoid incorrect or sub-optimal integration (e.g. inappropriate placement of heat pumps) (Philipp et al., 2016).

Please cite this article as: Atkins M.J., Neale J.R., Wu Y.-H., Walmsley M.R.W., 2018, Regional and national greenhouse gas emissions reduction planning , Chemical Engineering Transactions, 70, 19-24 DOI:10.3303/CET1870004

As a result of the top-down approach, important technical aspects of GHG reduction measures and their integration, are usually overlooked or trivialised.
A Process Integration approach/framework (based on Pinch Analysis) for estimating sector, regional and national GHG emissions reduction potentials from the industrial PH sector and developing marginal cost abatement curves (Huang et al., 2016) is presented in this paper. The basis of the framework develops process temperature demand profiles for heating and cooling demand, allows benchmarking and targeting to be carried out, and provides a standard to assess emissions reduction measures against. Preliminary results from an on-going study into New Zealand's industrial emissions will be presented as an example of how the framework can be applied and how the findings can be used to help form the evidence basis for policy development and to develop sector roadmaps for transitioning to low or zero emissions production.

2. Methodology

An overview of the framework of the methodology is shown in Figure 1. Energy and GHG emissions data by sector and process category is required to prioritise sectors/process to focus on. The prioritised sectors or processes are then investigated individually. A "typical" plant is modelled as a representative basis for the sector and should reflect the process flow/unit operations, plant equipment, and level of heat recovery. The model is a simplified mass and energy balance of the typical plant with enough detail to extract stream data and quantity of hot and cold utility use. The utility system can be approximated using assumptions of typical boiler efficiency etc. or can be modelled separately if more detail is required. A simple Pinch Analysis can then be performed using the stream data from the process model and utility targets compared against existing utility use. The goal is not to preform detailed heat exchanger network retrofit analysis but to simply determine an approximate magnitude of utility reduction achievable based on thermodynamics, changes in the operating costs, and indicative capital cost for each measure considered.

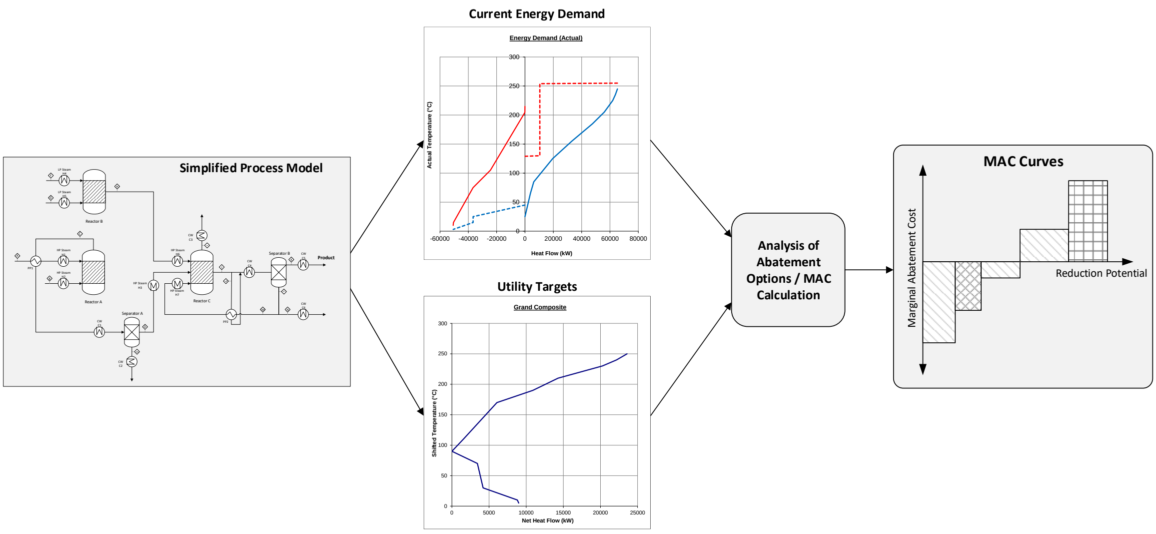

Figure 1: Overview of methodology framework for an individual process.

2.1 Marginal Abatement Costs

The process model, current energy demand and grand composite can then be used as a basis to determine abatement measures for GHG reductions. For each individual measure the emissions reduction can be quantified and extrapolated to estimate the total GHG reductions for that measure at a regional or national level for that process or sector. Operational (Opex) and Capital (Capex) costs for each measure can be estimated and used to calculate the Marginal Abatement Cost (MAC). The MAC can be calculated using Eq(1) or Eq(2) yielding the same result where n is the number of years the analysis is based on and is usually the expected equipment lifetime. The MAC should be calculated with a carbon cost of zero, as the interpretation of the MAC is the cost of carbon that would yield an NPV equal to zero (i.e. the total economic benefits/costs equal the total economic liability for those emissions). The tool to calculate MAC can be used to investigate different financial inputs (e.g. fuel costs, equipment lifetime, discount rate, etc.) and can be used to perform plant specific analysis, regional analyses, or national analyses.

$$MAC = \frac{-NPV}{\sum_0^n GHG\ Reductions} \tag{1}$$

$$MAC = \frac{\Delta Opex - Annualised\ Capex}{\Delta\ Anunal\ GHG\ Reductions} \tag{2}$$

2.2 Abatement Options

GHG emissions reduction or abatement options can be separated into demand reduction measures or supply reduction methods and further categorised into one of three categories under each heading. These are summarised, using examples, below.

Demand Reduction Measures

- Energy / Process Efficiency Improvements
  e.g. Heat recovery, process optimisation, mechanical vapour recompression
- Technological Change
  e.g. Alternate low energy processing technology, alternate process pathways
- Industrial Sector Transformation
  e.g. Change products to low emission alternatives (e.g. steel to wood)

Supply Reduction Measures

- Utility System Efficiency Improvements
  e.g. Boiler tuning and optimisation, heat recovery, increased condensate return
- Fuel Switching
  e.g. Biomass, wood pellets, renewable electricity, lower emissions fuel (i.e. coal to gas)
- Carbon Capture, Storage, and Utilisation

Abatement options can be compared using the MAC and their reduction potential. The relationship between options is also important to include because some may be dependent (i.e. option B maybe dependent on option A being implemented first) or mutually exclusive (i.e. cannot do both option C and option D). Based on the MAC and reduction potentials, policies can be developed to focus on the most cost effective abatement options which will meet the required target. If carbon cost is a policy instrument which can be altered, the MAC can be used as an indicator to determine what options will become cost effective or at least cost neutral and to evaluate the associated emissions reduction. Similarly, options with great potential that might need support can have targeted policy options developed (e.g. demonstration projects to de-risk implementation).

3. New Zealand Process Heat Sector

The next section will report preliminary results from an on-going study of New Zealand's industrial emissions. It will be presented as an example of how the framework can be applied.

3.1 Background

Under the Paris Agreement, New Zealand committed to an emissions reduction target of 30 % of 2005 levels by 2030, which equates to a required reduction in real terms of around 18 – 20 $Mt_{CO2\text{-}e}$ per annum. Furthermore, there is legislation being introduced into Parliament in late 2018 with the intent to set a target for net zero emissions by 2050. PH contributes around 25 % of national primary energy demand and 14 % of GHG emissions and has been identified as one of three key areas (along with transport and electricity) for targeted policy for large scale emissions reduction (MBIE, 2017a). NZ is somewhat unique in that around 50 % of emissions are from agriculture, which have limited scope for reductions in the medium to long-term horizon (Walmsley et al., 2015).

To assist in reducing PH emissions and to achieve reduction targets, the New Zealand Government is currently developing a process heat plan (PHINZ) as part of the New Zealand Energy Efficiency and Conservation Strategy 2017 – 2022 (NZEECS) (MBIE, 2017a). The goal of PHINZ is "to improve energy efficiency and the use of renewable energy in the process heat sector, and to build our evidence base to help achieve this" (MBIE, 2017b). NZEECS also contains a separate target for PH emissions reduction – at least a one per cent per annum average decrease in industrial emissions intensity ($kg_{CO2\text{-}e}$/\$ GDP_{real}). Industrial emissions intensity has been decreasing at an average rate of over 1 % per annum under business as usual conditions, but as the economy has grown so too have absolute GHG emissions from the industrial sector. It is clear that there are incongruous targets set out in NZEECS and that an improved evidence base on which to develop effective and coherent policy interventions is required.

3.2 National Process Heat Emissions and Marginal Abatement Curves

Several datasets contain energy demand and GHG emissions sources for the New Zealand industrial PH sector. Datasets often have large discrepancies between them and exclusions are sometimes made for various reasons including definitional issues or commercial sensitivity. For this analysis the several national data sets were harmonised by comparing energy and emissions use with production and expert input. In 2014, total net PH emissions were 10.7 Mt_{CO2-e} with 55.4 % of emissions coming from five energy intensive sectors (across six individual sites). Energy intensive sectors are sectors that require high temperatures, have large specific energy requirements and includes cement production, methanol synthesis, oil refining, and metals. The dairy sector is the other major emitter at 21.1 % of emissions, with an estimated 78 % of those arising from milk powder production. The other sectors such as meat, food and beverage processing are not significant sectors individually with less than 6 % of emissions per sector. Figure 2 illustrates GHG emissions by industrial sector separated by process category (process category labels has been omitted). As shown by the cumulative emissions curve in Figure 2, 90 % of emissions are covered by only 14 processes (out of a total of 41). A large portion of the total emissions can be captured by focusing on the top processes and some options (e.g. heat pumps for waste heat upgrading) will have applicability across multiple sectors.

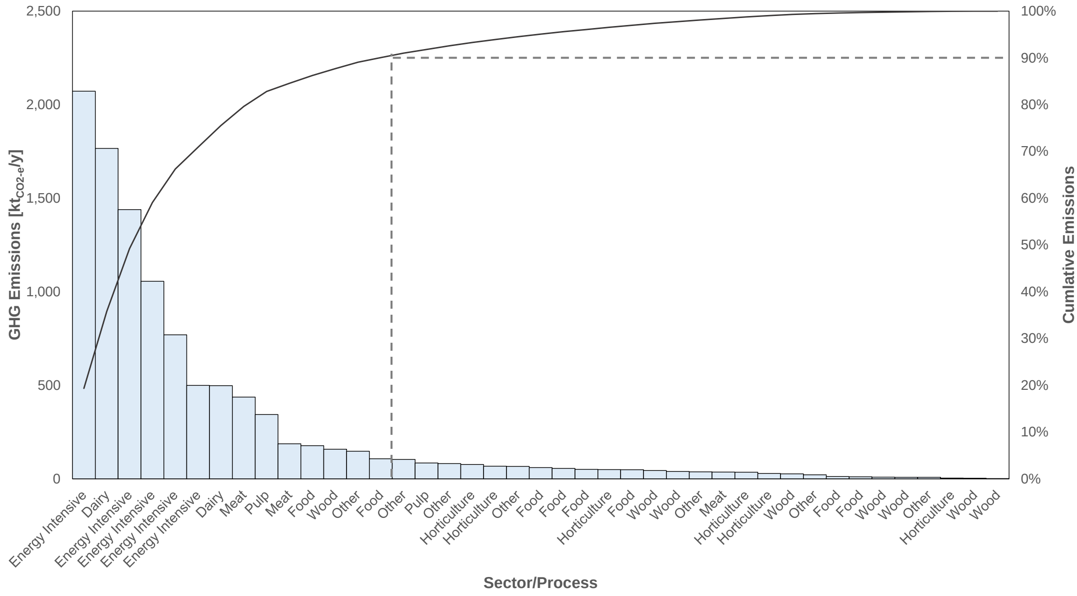

Figure 2: New Zealand GHG emissions from industrial sectors separated by process category.

Simplified process models for selected processes have been developed based on “typical” NZ plants. Where appropriate, multiple models for a single process have been developed to reflect different technologies used by plants. It is important that these models reflect actual current processes, unit operations and practices, which requires some expertise and knowledge of the sector. Individual abatement options were examined and the reduction in PH demand/emissions were calculated using the developed models. MAC for each abatement option was calculated and MAC curves developed. A negative MAC cost indicates a positive NPV (i.e. a cost effective measure). It should be noted that even though these projects have positive NPVs these may not meet internal company thresholds for investment or there may exist other barriers to widespread implementation. All MAC presented here are in New Zealand Dollars, use a discount rate of 6 %, equipment life of 15 years, and indicative 2017 industrial fuel and electricity costs.

MAC curves for two processes are shown in Figure 3 and Figure 4. Both are sector weighted curves (i.e. the inputs into the model are sector weighted for costs, fuel use, and total emissions). Individual abatement options are labelled (in general terms). Based on the curves there is approximately 450 kt_{CO2-eq} (35 %) and 205 kt_{CO2-eq} (70 %) reductions that can be achieved at negative carbon costs for Process A and B respectively. For Process A much of the cost effective reductions come from process electrification measures (e.g. heat pumps, mechanical vapour recompression, etc.), increased heat recovery, and utility system efficiency improvement. Modest reductions can be achieved through further process electrification at a carbon cost of around $ 36/t_{CO2-e}. Fuel switching offers the largest reduction potential although at high MAC (>$ 100/t_{CO2-e}). Fuel switching to RE (e.g. direct heating or using electrode boilers) had the highest MAC due to the relatively high cost of RE compared to other fuel options and these having no Coefficient of Performance (COP) benefit.

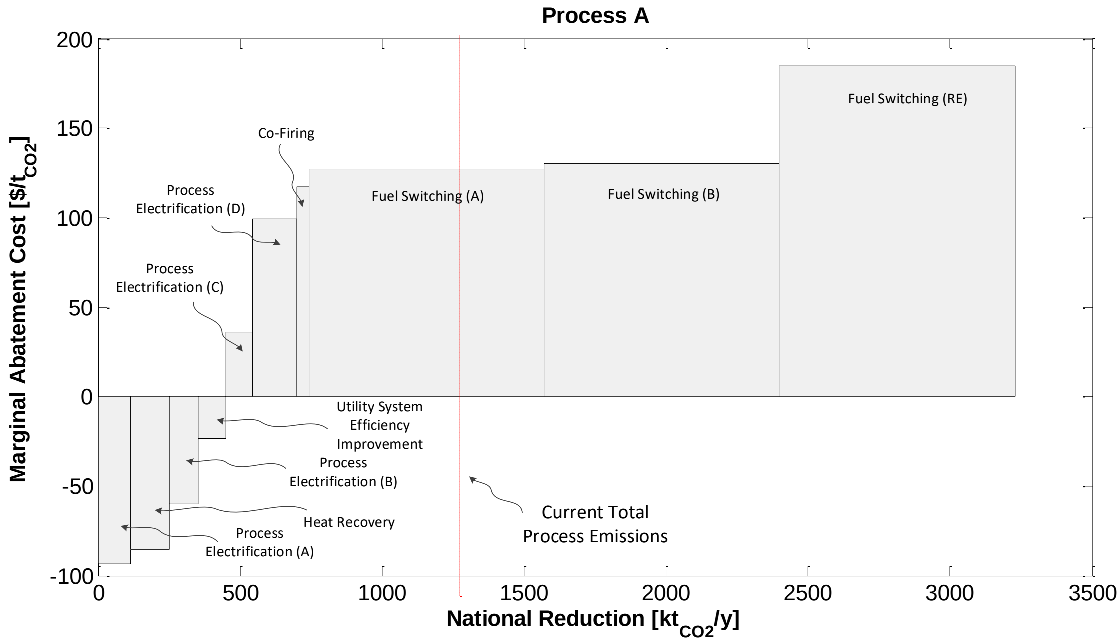

Figure 3: Sector weighted Marginal Abatement Cost Curve for exemplar Process A ($=NZD).

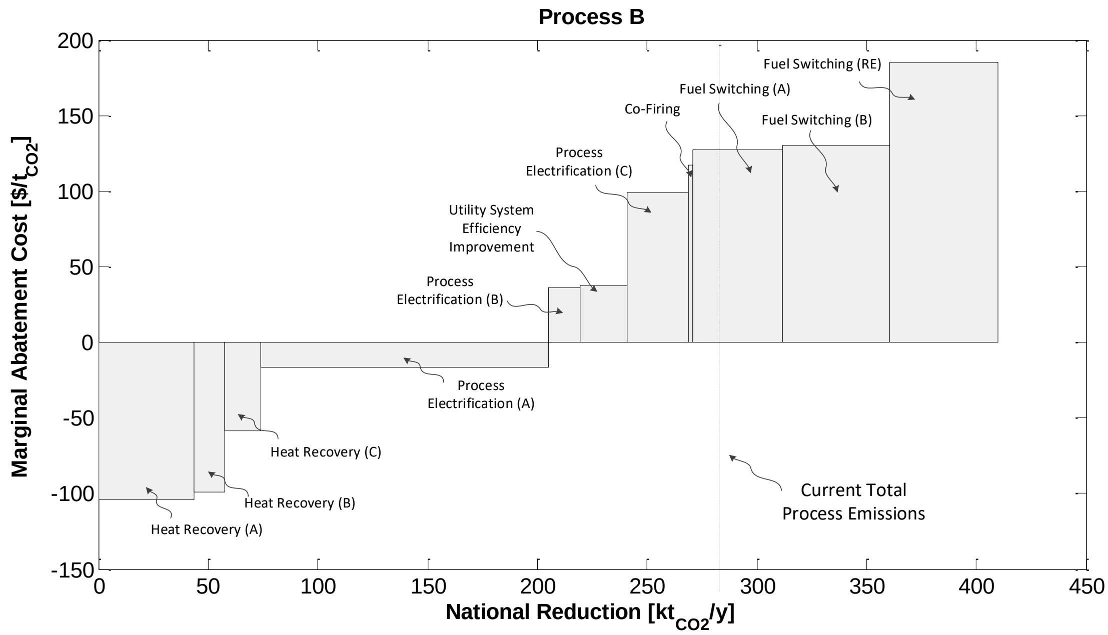

Figure 4: Sector weighted Marginal Abatement Cost Curve for exemplar Process B ($=NZD).

The most cost effective options for Process B are increased heat recovery followed by process electrification; however it should be noted that some of these options are mutually exclusive (i.e. they cannot be all be implemented together). In this case, Heat recovery (A) and Process electrification (A) cannot be performed together. For both Process A and B the total emissions from all of the measures are greater than the current total emissions from that sector indicating there is some choice between options and also some mutually exclusive options. To reach a complete reduction in net GHG emissions from these two processes it is clear from the MAC curves that carbon costs would need to be well in excess of \$ 100/t$_{CO2\text{-}e}$ to make the required measures at least cost neutral. In 2017, the NZ carbon price was approximately \$ 20/t$_{CO2\text{-}e}$. The two processes considered together show that a total of around 605 kt$_{CO2\text{-}e}$ can be economically achieved at current carbon costs, which represents a 6 % reduction in overall reduction in industrial emissions. Efforts to encourage the specific heat recovery and process electrification measures identified will be vital in assisting and managing the economic transition for these sectors. Further work is continuing on other priority sectors.

Although MAC curves are useful for comparing the relative cost of different options, there are some limitations and caveats that are important to appreciate their interpretation (Kelsicki and Ekins, 2012). These include ensuring a consistent baseline between measures and between individual MAC curves, eliminating double counting of emission reductions, capturing the interdependence of measures, and stating the assumptions of the MAC calculation. Two important limitations are the lack of intersectoral and intertemporal considerations and the absence of co-benefits (e.g. air or water quality improvements). Because analysis of abatement options is based on PI principles, the options have been integrated in an appropriate manner and many of the issues with MAC curves have been addressed or minimized. The curves can be used as an additional evidence basis, grounded in rigorous engineering and PI analysis, to develop targeted policies (e.g. by sector or abatement option). The MAC and the quantity of potential reduction can also be used to conduct not just macro-level analysis of regional or national transitions, but also site level roadmaps to low emissions production. Eroy et al. (2018) suggest different policy tools are required to target different ranges of MAC options. For example, abatement measures with high negative MAC should not require direct financial support but are best suited to information campaigns and technical support. The best policy tools will depend on specific political, economic, and social conditions in each country. However, the development of effective policy tools can be informed MAC curves that are based on rigorous engineering based analysis of the options including PI considerations.

4. Conclusions

Developing effective policy interventions to reduce GHG emissions from industrial process heat is essential to achieve large scale reductions. The evidence base to develop these policies is often incomplete and contradictory. Using a Process Integration framework to quantify emissions reduction potential and Marginal Abatement Costs for individual reduction measures for selected process can provide important, bottom-up based analysis, on which to base policy interventions. Based on preliminary results from an on-going study into New Zealand's industrial process heat emissions, the Marginal Abatement Cost Curves for selected two processes, there exists substantial reductions with negative Marginal Abatement Costs (i.e. projects that are currently economically beneficial). Policy interventions should therefore focus on reducing the barriers to widespread adoption and implementation of these measures.

References

Atkins M.J., 2016, Choice cuts, TCE The Chemical Engineer, 899, 25–29.

Chapman A., McLellan B., Tezuka T., 2016, Strengthening the energy policy making process and sustainability outcomes in the OECD through policy design, Administrative Sciences, 6, 9–25.

Eory V., Pellerin S., Garcia G.C., Lehtonen H., Licite I., Mattila H., Lund-Sørensen T., Muldowney J., Popluga D., Strandmark L., Schulte R., 2018, Marginal abatement cost curves for agricultural climate policy: State-of-the-art lessons learnt and future potential, Journal of Cleaner Production, 182, 705–716.

Huang S.K., Kuo L., Chou K-L., 2016, The applicability of marginal abatement cost approach: A comprehensive review, Journal of Cleaner Production, 127, 59–71.

Jacobson H.K., 1998, Integrating the bottom-up and top-down approach to energy-economy modelling: the case of Denmark, Energy Economics, 20, 443–461.

Kesicki F., Ekins, P., 2012, Marginal abatement cost curves: a call for caution, Climate Policy, 12, 219–236.

Kranzl L., Hummel, M., Müller, A., Steinbach, J., 2013, Renewable heating: Perspectives and the impact of policy instruments, Energy Policy, 59, 44–58,

MBIE, 2017a, New Zealand Energy Efficiency and Conservation Strategy 2017 – 2022, Ministry of Business, Innovation & Employment <mbie.govt.nz/info-services/sectors-industries/energy/documents-image-library/NZEECS-2017-2022.pdf> accessed 21.03.2018.

MBIE, 2017b, Process heat in New Zealand, Ministry of Business, Innovation & Employment <mbie.govt.nz/info-services/sectors-industries/energy/energy-efficiency-environment/process-heat-in-new-zealand> assessed 21.03.2018

Philipp M., Schumm G., Peesel R-H., Walmsley T., Atkins M.J., Hesselbach J., 2016, Optimal energy supply structures for industrial sites in different countries considering energy transitions: A cheese factor case study, Chemical Engineering Transactions, 52, 175–180.

Walmsley M.R.W, Walmsley T.G., Matthews L., Atkins M.J., Neale J.R., Kamp P.J.J., 2015, Pinch Analysis techniques for carbon emissions reduction in the New Zealand industrial process heat sector, Chemical Engineering Transactions, 45, 1087–1092.