Energy 76 (2014) 336–344

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Marginal abatement cost curves and abatement strategies: Taking option interdependency and investments unrelated to climate change into account

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A R T I C L E I N F O

Article history:
Received 4 March 2014
Received in revised form
2 August 2014
Accepted 6 August 2014
Available online 6 September 2014

Keywords:
MACC
CO_2 abatement
Investment optimization

A B S T R A C T

Firms usually have optimization tools for evaluating various investment options; policymakers likewise need tools for designing economically efficient policies. One such tool is the MACC (marginal abatement cost curve), used to capture the least-cost sequence of abatement options. Such curves are also used for understanding the implications of government policies for markets and firms. This article explores dynamic path-dependent aspects of the Stockholm district heating system case, in which the performance of some discrete options is conditioned by others. In addition, it proposes adding a feedback loop to handle option redundancy when implementing a sequence of options. Furthermore, in an energy system, actions unrelated to climate change abatement might likewise affect the performance of abatement options. This is discussed together with implications for climate change policy and corporate investment optimization. Our results indicate that a systems approach coupled with a feedback loop could help overcome some of the present methodological limitations.

1. Introduction

The mechanisms used to mitigate climate change generally entail decision-making regarding technology investment and adopting a least-cost planning approach to sustain competiveness. In the context of energy systems, this involves both interaction with present systems and the performance of discrete options. The long technological life of many energy-related investments does not make analysis easier.

One important instrument for policymakers and industry when studying possible abatement options is MACCs (marginal abatement cost curve). MACCs are used to analyse investments and the impact of policy measures in order to find the least-cost options to achieve a certain target, such as climate change mitigation. MACCs are also used to analyse market reactions to economic policy, such as the effects of the Kyoto Protocol, and to assess policies, such as the Europe 2020 strategy [23,24,34].

This paper aims to develop the methodology of expert-based MACCs for least-cost investment planning in circumstances in which the options are not only interdependent but also dependent on developments external to the climate change discourse. While the existing literature on MACCs discusses the influence of path-dependency and local contexts see, e.g., [5,9,34], it does not take interdependencies fully into account [22]. claim that it is unclear to what extent interactions between abatement options are included in present MACCs based on discrete options, and recommend applying a systems approach. All else being equal, major events, which are sometimes external to the climate change mitigation discourse, that condition and influence the properties of the options considered remain relevant. The magnitude of such effects would vary between contexts. In larger energy systems, such as the Nordic or European power markets, changes related to individual power plants would have a smaller effect than would similar changes in a DH (district heating) network. On the other hand, the aggregated changes that are often the focus of broader MACCs [30] provide conditions in which interdependencies exist. This research gap will be addressed here.

The contribution of this article lies in exploring the dynamic, path-dependent aspects whereby certain abatement alternatives condition others, including the effects of option sequence and major events not traditionally included in MACC analyses.

To provide an illustrative example, we have chosen to analyse planned developments and possible abatement options for the south/central Stockholm DH network. This energy system is small enough to be predictable but large enough to enable analysis and discussion to reach general conclusions valid for other energy systems.

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http://dx.doi.org/10.1016/j.energy.2014.08.025
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2. Marginal abatement cost curves

At a national level, abating GHG (greenhouse gas) emissions at the lowest cost to society is among the most important tasks when designing climate change policy [6]. In the same way, a profit-maximizing firm aims to find the lowest-cost GHG abatement options [5]. This task includes many possible strategies with regard to installed capacity and technology, as well as changes in production processes.

Recently increased interest in MACCs stems largely from reports from the consultancy firm McKinsey & Company [23]. In the USA and the European Union, these curves have been important tools for assessing the costs of emission reductions, supporting recommendations by many NGOs, such as the World Bank. At the European level, MACCs are used to estimate the price of a certain amount of emission allowances within the EU ETS (European Union Emission Trading Scheme). [13] discuss an example that treats the possibility of including road transport in the EU ETS to meet abatement targets. Another use of MACCs is to analyse what abatement options are possible given a specific allowance price [37]. The model is also used for more local assessments, such as developments in single countries, industries, and technologies see, e.g., [2,26,36,38,42,45]. Studies analysing the MAC (marginal abatement cost), but without using a curve, are also common, for example, the cost analysis of carbon capture under different policy scenarios [35] and the optimization of NGCC (natural gas combined cycle) power plants [4]. Outside Europe, MACCs have been used, for example, in research into optimizing the Chinese cement industry [44] and evaluating climate change policy in Brazil [33]. The curves have also been applied to the abatement of emissions other than CO_2, such as SO_x emissions in the USA [41].

Although MACCs might be regarded as recent tools used to appraise climate change mitigation, their application started in the 1970s when the global economy was hit by the oil crises. Referred to as savings curves or CSCs (conservation supply curves), their goal was initially to evaluate energy efficiency and provide options for improvements at both the plant and policy levels see, e.g., [32,39]. The model is also used in this way today, for example, in the research of [16] and [7].

In production theory, the explanation behind the curves is centred on the fact that if part of a process is viewed as inappropriate, the curves represent the marginal loss in profit of changed production, or the MC (marginal cost) of achieving a target [24]. As investments may provide a positive financial return, a negative MC is also common. In essence, devising and analysing MACs provide insights into how to achieve a target through possible options, as they correspond to the additional costs or benefits of possible actions to fulfil a unit of the target.

At the plant level, MACCs can be used to link the individual plant's emission levels to the cost of additional emission abatement, i.e., MA (marginal abatement), relating to specific actions and technologies. In a CO_2 context, MACCs are usually illustrated with tonnes of avoided CO_2 emissions on the x-axis and costs per reduced tonne of CO_2 on the y-axis [9,23]. The total abatement cost of a set target then corresponds to the total area under the MACC from zero to that target on the x-axis, so the total cost depends on both the reduction target and the shape of the MACC [9,34].

A MACC could be created using either an expert or model-based approach depending on the dataset available [19,23]; however, it is worth noting that other classifications might also be used see, e.g., [10,24,43].

Of the model-based approaches, the *top–down approach* is usually a macroeconomic approach, generally implemented using equilibrium models [9,24,34], such as the EPPA (Emission Prediction and Policy Analysis) model developed at MIT, and other energy system models analysing the relationship between environmental policy and the impact of technical change [3]. The top–down approach is concerned with how markets respond to exogenous pressures, such as an assumed or pending policy intervention and its implications for a system. In this context, MACCs could cover the economy as a whole [20]. Analysing the exogenous mechanisms that influence the system would allow abatement costs to be calculated from a welfare perspective [9]. From this perspective, it has been argued that all taxes and subsidies should be excluded from MAC analyses, as they are only transferred between groups within society [23]. In addition, the top–down approach could be used at the industry level, where it would often include the detailed and exhaustive analysis of issues such as policy tilt pricing and production costs [24]. In the other model-based approach, the *bottom–up approach*, the marginal costs are derived from energy system optimization models [9]. A recent example of this approach applied in the CSC context is that of [15].

The other dominant approach is the *expert-based approach*, which is underpinned by an engineering or expert mindset incorporating the detailed analysis of various discrete options. [10,43], and [41] categorize this as a type of bottom–up approach. The difference between these authors and [23] and [_Taylor_2012] seems to lie in their categorization between expert-based as a bottom-up approach on the one hand, and bottom-up as a model based on the other. All the relevant literature, however, agrees on the definition of the expert-based approach, which is generally based on individual estimations of particular alternatives. The approach seeks to find the best possible (i.e., lowest cost) options for achieving a target within a given context. From a corporate perspective, expert-based MACCs answer the questions of how the market will or should adapt to policy and what the best available options are for future investments and actions. The expert-based approach has been the most common approach in MACC analysis [23]. If a firm is a price taker, prices might be treated as fixed and could thus mirror the actual price scenario a firm expects under this approach.

The local context of technological lock-ins, path dependency, and other barriers could affect a firm's decisions [1]. It may turn out that the paths entered into by firms are incompatible with the rest of the system [5]. An important aspect of MAC analysis is that structural factors might have a huge impact, and the results of similar abatement options might vary between different regional and local contexts. Initially, a low market price for energy relative to the introduced cost of CO_2 emissions would mean increased effects of the abatement policy [9].

The supply structure of the energy industry affects the marginal cost of adopting a substitute. The costs of abatement options are significantly lower in an energy system where direct substitutions of natural gas for coal are possible, compared with a system, for example, in which such a switch has already taken place.

The original CSC literature took option interaction into account through an iterative process wherein the lowest-cost option would

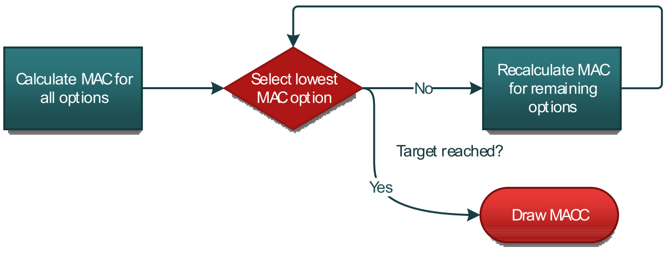

Fig. 1. The iterative methodology of the original CSC approach in a MAC optimization context.