The Y factor for Climate Change abatement – A method to rank options beyond abatement costs

Chappin, E. J.L.; Soana, M.; Arensman, C. E.C.; Swart, F.

DOI
10.1016/j.enpol.2020.111894

Publication date
2020

Document Version
Final published version

Published in
Energy Policy

Citation (APA)
Chappin, E. J. L., Soana, M., Arensman, C. E. C., & Swart, F. (2020). The Y factor for Climate Change abatement – A method to rank options beyond abatement costs. Energy Policy, 147, [111894]. https://doi.org/10.1016/j.enpol.2020.111894

Important note
To cite this publication, please use the final published version (if applicable).
Please check the document version above.

Copyright
Other than for strictly personal use, it is not permitted to download, forward or distribute the text or part of it, without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license such as Creative Commons.

Takedown policy
Please contact us and provide details if you believe this document breaches copyrights.
We will remove access to the work immediately and investigate your claim.
The Y factor for Climate Change abatement – A method to rank options beyond abatement costs

E.J.L. Chappin *, M. Soana, C.E.C. Arensman, F. Swart

Faculty of Technology, Policy and Management, Delft University of Technology, The Netherlands

**A R T I C L E   I N F O**

**Keywords:**
Climate abatement
Adoption barriers
Climate and energy policy
Behaviour
Multi-actor complexity
Investments

**A B S T R A C T**

The tools available to translate climate targets into abatement actions are mainly based on costs and technical feasibility. Options for greenhouse gas abatement span all sectors, all countries, and involve a huge variety of technologies. The reasons for abatement to be realized, or not, are diverse and complex. In particular, the political discussion why many affordable options do not materialize is naïve and ad hoc. Here we show the Y factor, an approach for a quick scan of abatement options against a set of prominent abatement barriers. We define 12 factors which capture a broad set of barriers related to 1) costs and financing, 2) multi-actor complexity, 3) physical interdependencies and 4) behaviour. We rank 24 abatement options using an explicit, but coarse scoring factor which shows why it may be difficult for options and sectors to interact, and for ignoring possible ancillary benefits (Kesicki and Ekins, 2012). Furthermore, ranking options at negative abatement costs is conceptually problematic (Taylor, 2012). Despite the fact that scenario studies using integrated assessment models (IAMs) incorporate many complexities, a focus on (lowest) cost abatement paths prevails and the concept of feasibility receives little attention (Anderson and Jewell, 2019). The reasons for abatement to be realized or not are diverse (Intergovernmental Panel on Climate Change, 2014) and depend on complex socio-economic dynamics (Edwards, 2011). This requires complementary tools alongside MAC curves and IAMs.

We propose the Y factor which shows why it may be difficult for abatement options to materialize by means of a quick scan of options against a variety of implementation barriers. The Y factor scores abatement options on 12 barriers in four groups: 1) costs and financing, misinterpret MAC curves and use them for prioritizing actions (Ward, 2014). Low cost abatement options appear desirable but there may be sufficient reason to assume they are not the easiest to implement. MAC curves have been criticized for a lack of transparency, the fact that important uncertainties (such as the discount rates (Kesicki and Strachan, 2011)) are often hidden, for the lack of dynamics, for the inability to show how options and sectors interact, and for ignoring possible ancillary benefits (Kesicki and Ekins, 2012). Furthermore, ranking options at negative abatement costs is conceptually problematic (Taylor, 2012). Despite the fact that scenario studies using integrated assessment models (IAMs) incorporate many complexities, a focus on (lowest) cost abatement paths prevails and the concept of feasibility receives little attention (Anderson and Jewell, 2019). The reasons for abatement to be realized or not are diverse (Intergovernmental Panel on Climate Change, 2014) and depend on complex socio-economic dynamics (Edwards, 2011). This requires complementary tools alongside MAC curves and IAMs.

We propose the Y factor which shows why it may be difficult for abatement options to materialize by means of a quick scan of options against a variety of implementation barriers. The Y factor scores abatement options on 12 barriers in four groups: 1) costs and financing, misinterpret MAC curves and use them for prioritizing actions (Ward, 2014). Low cost abatement options appear desirable but there may be sufficient reason to assume they are not the easiest to implement. MAC curves have been criticized for a lack of transparency, the fact that important uncertainties (such as the discount rates (Kesicki and Strachan, 2011)) are often hidden, for the lack of dynamics, for the inability to show how options and sectors interact, and for ignoring possible ancillary benefits (Kesicki and Ekins, 2012). Furthermore, ranking options at negative abatement costs is conceptually problematic (Taylor, 2012). Despite the fact that scenario studies using integrated assessment models (IAMs) incorporate many complexities, a focus on (lowest) cost abatement paths prevails and the concept of feasibility receives little attention (Anderson and Jewell, 2019). The reasons for abatement to be realized or not are diverse (Intergovernmental Panel on Climate Change, 2014) and depend on complex socio-economic dynamics (Edwards, 2011). This requires complementary tools alongside MAC curves and IAMs.

We propose the Y factor which shows why it may be difficult for abatement options to materialize by means of a quick scan of options against a variety of implementation barriers. The Y factor scores abatement options on 12 barriers in four groups: 1) costs and financing,
2. Methodology: the Y factor

The Y factor was first developed, tested and theoretically grounded. Afterwards, it was applied to a prominent set of abatement options. Finally, the Y factor was used with policy makers.

2.1. The Y factor

The Y factor is determined by scoring an abatement option on each factor (i.e. assigning 0, 1 or 2); each abatement option can, therefore, have a total score between 0 and 24. Table 1 gives an overview of the factors, and how the factors and scores are defined. Though the different barriers are not necessarily comparable, the application of the Y factor captures why (Y) an abatement option may be difficult to materialize (in addition to abatement cost levels).

Barriers for abatement are represented in Y factors generic enough to be applicable to all sectors, while being explicit and operational enough that they can be scored on a 0–2 scale. While most of the sector-specific barriers as described by the IPCC (Intergovernmental Panel on Climate Change, 2014) are captured, Y factors are typically formulated in more practical terms (Arensman, 2018). This is essential for the Y factor to be effective in comparing abatement options across sectors and for a broad set of barriers. The Y factors are rooted in a socio-technical systems perspective (Bijker et al., 1987): realising abatement options implies changes in large-scale socio-technical systems, where technologies are used differently and/or replaced with others, thereby avoiding greenhouse gas emissions. This perspective translates into these four categories:

1) Abatement options that replace (or introduce) technologies – being more efficient or using different energy sources/carriers – require investments (Dixit and Pindyck, 1994). This leads to barriers on costs and financing, for which the significance of an investment, the payback time and issues related to financing are well known criteria. The factors are framed to the investor so that it is not the absolute sum which is relevant, but whether it is significant for who is paying.

2) Decisions in socio-technical systems are made by a wide variety of individual actors, who are not all able to decide unilaterally; they operate in stakeholder networks (Brujin and Herder, 2009). Multi-actor complexity is caused by key decisions depending on others, by the influence of others with opposing values and interests (Weisbuch et al., 2008) (including public acceptance issues), and by the institutions determining the roles and responsibilities which, in turn, may enable or hamper actors’ abatement decisions (Williamson, 1998).

3) Abatement implies intervening in existing technological systems (Hughes, 1987). This feeds the category of physical interdependencies (Herder et al., 2008), which captures well-known barriers related to whether changes are required in embedded physical systems, such as infrastructures, whether current technical operations need to be interrupted, and whether the technology has been fully proven.

4) Abatement relates to actors’ behaviour whose rationality is bounded, affecting which abatement options are considered and when (Foxon, 2006). This implies, behaviour is limited to the knowledge about abatement options, and to when opportunities arise that put abatement decisions on the table. Additionally, abating can rely on changes in behavioural patterns (Hesselink and Chappin, 2019).

Table 1: List of factors, Y factors, values and definitions. Each abatement measure scores either 0, 1, or 2 on each of the factor. Scoring 0 suggests that there is no barrier for the factor in question; scoring 1 suggests a possible barrier, scoring 2 suggests a significant barrier.

| Category | Factor | Value 0 | Value 1 | Value 2 |
|----------|--------|---------|---------|---------|
| Costs and financing | Investment cost required | Low | Medium | High |
| | Difficulty in financing | Absent | Medium | Large |
| | Expected pay-back time | <3 years | 5-12 years | >12 years |
| | Degree of technological risk | Absent | Slight | Severe |
| | Degree of technological reliability | Unclear | Medium | Large |
| | Degree of technological performance | Poor | Medium | Large |
| Multi-actor complexity | Dependence on other actors | No | Little | Much |
| | Diversity of actors involved | No | Slight | Severe |
| | Division of roles and responsibilities | No | Slight | Severe |
| | Knowledge of actors | No | Slight | Severe |
| | Frequency of opportunity | No | Slight | Severe |
| | Change in behaviour | No | Slight | Severe |
| Physical interdependencies | Physical embeddedness | No | Slight | Severe |
| | Dependency of actors involved | No | Slight | Severe |
| | Degree of technological uncertainty | No | Slight | Severe |
| | Degree of technological vulnerability | No | Slight | Severe |
| | Degree of technological performance | No | Slight | Severe |
| | Frequency of opportunity | No | Slight | Severe |
| | Change in behaviour | No | Slight | Severe |
2.2. Development of the Y factor definitions

A preliminary version of the Y factor, illustrated with a preliminary scoring was presented in (Chappin, 2016). Factor definitions were systematically reviewed and theoretically grounded and revised. This resulted in a Y factor that allows for a coarse scoring of 0 (no barrier), 1 (possible barrier), or 2 (significant barrier) for an abatement option on the basis of 12 factors. Final definitions (as revised for this manuscript) are in Table 1 in the main text.

The sector-specific barriers mentioned in the IPCC report from five sectors (Intergovernmental Panel on Climate Change, 2014) and theory on transition and system innovation (e.g. (Geels, 2002; Hekkert et al., 2007; Loorbach and Kemp, 2005); see also sections 2.3 and 2.4 of (Arensman, 2018)) underpin the four Y factor categories: a broad diversity of sector-specific and conceptual barriers in the literature, relate to these categories, such as range anxiety (that typically applies to electric vehicles) linking to the behaviour category.

Detailed case studies for four distinct abatement options by means of three to four semi-structured interviews per case with Dutch experts from business, government and academia demonstrated the relevance of all individual Y factors (section 3.5 and chapter 4 in (Arensman, 2018); this led to further refinement of factor definitions (section 5.3 of (Arensman, 2018)).

2.3. Application of the Y factor

We developed scores for each abatement option on the basis of a broad set of recent literature and validated these scores with sector experts. A complete overview of sources for the initial scoring are in chapter 2 of (Soana, 2018) (publicly accessible). The scores were validated with sector experts from research institutes and universities in various countries (names and affiliations mentioned on page 46 of (Soana, 2018)) by means of semi-structured interviews. Two to three sector experts from in total five countries (Germany, Italy, the Netherlands, the UK, and Mexico, further details in chapter 4 of (Soana, 2018)) validated 80% of the scores, the remainder was validated by one expert. 8% of the scores are significantly uncertain. We concluded that the scoring is robust against the selection of experts.

2.4. Use of the Y factor results

The Y curve is presented through an interactive website (http://emlab.tudelft.nl/yfactor/) that invites discussion amongst climate policy makers in terms of the arguments supporting the scoring, the need and desired direction for climate policy and the robustness of the Y factor curve (Swart, 2019). Focus groups with 6 senior and 3 junior climate policymakers and strategists from the Netherlands confirmed the ability of the interactive Y factor website to generate discussion on prioritization of abatement options beyond abatement costs, and the ability to discuss key elements needed in the climate policy debate (chapter 5 of (Swart, 2019)).

3. Results and discussion

We present the Y factor curve in Fig. 1. The curve was developed and

![Y factor scoring of 24 abatement options. Each abatement option is represented as a bar. Factors scoring either 1 or 2 are visible. Options are sorted from low to high Y scores. See http://emlab.tudelft.nl/yfactor/ for an interactive version.](http://emlab.tudelft.nl/yfactor/)

Table 2

| ID | Abatement option                      |
|----|---------------------------------------|
| 1  | Agronomy practices                    |
| 2  | Air transport                         |
| 3  | Battery Electric Vehicles              |
| 4  | Bioethanol lignocellulosic            |
| 5  | Building efficiency new built         |
| 6  | Cars full hybrid                      |
| 7  | Cars plug-in hybrid                   |
| 8  | Clinker substitution by fly ash       |
| 9  | Coal CCS new built                    |
| 10 | Coal CCS retrofit                     |
| 11 | Composting new waste                  |
| 12 | Cropland nutrient management          |
| 13 | Electricity from landfill gas         |
| 14 | Energy efficiency 1 iron & steel      |
| 15 | Geothermal                            |
| 16 | Grassland management                  |
| 17 | High penetration wind                 |
| 18 | Lighting switch to LED (residential)  |
| 19 | Nuclear energy                        |
| 20 | PV panels homes                       |
| 21 | Reduced deforestation (agriculture)   |
| 22 | Reduced deforestation (timber harvesting) |
| 23 | Residential appliances                |
| 24 | Small hydro                           |
validated for 24 abatement options (Soana, 2018) from McKinsey’s most recent MAC curve (Nauclér and Enkvist, 2009), listed in Table 2. We deliberately selected options from this curve to be able to illustrate similarities between McKinsey’s MAC curve and the Y factor curve. We focus on effective measures; our selection contains primarily high abatement potential options from various sectors. Fig. 2 illustrates the correlation between the barriers identified with the Y factor method, and the abatement costs and potentials originating from (Nauclér and Enkvist, 2009). The curve essentially has a global scope, capturing the most appropriate values for the factors world-wide. Where more specific choices were in order, simply because the values depend on local rules, regulations, institutions or culture, we chose the conditions in Europe and the Netherlands to underpin our choices. We interpret the results from Figs. 1 and 2 (section 3.1), discuss the robustness of these results (section 3.2) and elaborate on their usability (section 3.3).

3.1. Interpretation of the Y curve

In general, abatement options score relatively high (at an average score somewhat above 10) which confirms that – besides abatement cost – emission reductions are hard to achieve. The options with the lowest number of barriers are on the left in Fig. 1. LED lighting, full hybrid vehicles are options that are penetrating in the market in the last decade and they are cost effective. The options with the largest number of barriers are on the right. Coal CCS new built and retrofit are options that have shown to be very hard to implement (Viebahn and Chappin, 2018) and also have the highest abatement costs in the set of options except for battery electric vehicles.

For the options in the middle, flatter portion of the curve, the relation between abatement costs and barriers withholding implementation is less straightforward. Prime examples of cost-effective abatement options with significant barriers are residential appliances and bioethanol lignocellulosic. 15 out of 24 abatement options have at least one significant barrier (represented in the scoring with a 2), withholding implementation. The other 9 abatement options all have possible barriers (represented in the scoring with a 1). For the latter options, the number of possible barriers range from 2 to 10. For two of the 24 abatement options (Coal CCS retrofit and Bioethanol lignocellulosic) barriers were identified for all 12 factors.

3.2. Robustness of the Y curve

We have shown that the Y factor scores are robust. In order to develop unambiguous scoring, a clear definition and appropriate scoping of abatement options are required (Arensman, 2018). Rigorous scoping is necessary because geographic/spatial aspects, economic and social conditions influence some of the Y factor values. The ranking provided by the curve does not equate to political prioritization; it provides insight in the number and significance of the implementation barriers that could be expected. It is robust in the latter context. The ranking’s edges, i.e. the low (left) and high (right) side are particularly stable against individual differences in barriers due to regional conditions or cultural factors. For the middle, flatter part of the curve, the ranking is more sensitive to changes in the individual scores. These sensitivities in the Y curve translate to crucial elements in the policy debate (see also section 3.3): i.e. 1) to apply focus in the debate on options with barriers that are addressed by existing or easily achievable policies, and/or 2) to consider whether it may be more appropriate to deal with multiple possible barriers (scores of 1) or to aim to eradicate fewer significant ones instead (scores of 2).

We have shown that scores are stable in time, except for when technologies or economic and social conditions evolve significantly (Arensman, 2018) (e.g. cost reductions for offshore wind or with new fixtures and better quality of LED lights). The scores are also robust against many uncertainties known to affect abatement: many do not affect the scoring because the uncertainty fits within the definition of the factors themselves or within the range covered in a particular score (e.g. developments in costs may reduce payback time, but it may stay within one of the ranges in Table 1). The scores may only change due to significant technological improvements, developments in infrastructure, in institutions, or in public acceptance, which would be reasons to revisit the curve.

3.3. Usability and limitations of the Y curve

The focus groups confirmed the interpretation of results and analysis...
of robustness above: climate policymakers desire tools that go beyond merely abatement costs and potentials and the Y factor tool can be used to develop a better understanding of the implementation complexities. The first contribution to the policy process is the initial ranking that is provided by the Y factor scores. It enables a quick analysis in terms of ‘if we want to implement this abatement option, we need to deal with these barriers’. The interactive website of the Y factor fuels an adequate climate policy debate (see page 71 of (Swart, 2019)) by readily providing a systematic overview of Y factor definitions, the scores on each of the barriers, and arguments for those scores, together with abatement costs and potentials that are of (Naucler and Enkvist, 2009). The Y curve may help the discussion by an initial focus on attractive options in terms of the number and significance of barriers (in addition to the two MACC dimensions - abatement potentials and costs), before moving to the detailed context and content of particular abatement options.

The Y factor intends to structure the policy process and provide important arguments in the policy debate. The Y factors do not include all systemic effects of each option, as aiming to include all those effects would obfuscate the overall gist of the method: being fully transparent while enabling a coarse scoring of abatement options against a wide variety of barriers. Furthermore, the different abatement options tap into different value systems and these may differ between cultures and affect political choices. Much of this is beyond the scope of the Y factor. Nevertheless, within the context of the Y factor, scores can be further specified to particular geographic areas or socio-economic conditions.

Subsequently, the robustness of the Y scores (including the resulting ranking of abatement options) can be further explored by varying factors’ weights, which is possible with the interactive website. Reasons to do so could be related to cultural or locational aspects, for instance where in some regions (and possibly sectors) financial aspects may be more dominant than in others. Applying factor weights for other purposes than checking robustness is a normative approach to using the Y factor tool. The Y factor is beyond the scope of this paper. Additional (e.g. cultural or economic) theory would be needed in order to validate such choices.

4. Conclusions and policy implications

The Y factor is a tool for a quick scan that illustrates which barriers may deem significant for a wide range of abatement options. This enables a rich discussion on prioritization of abatement options and provides an overview of key elements needed in the policy debate; we have shown it provides structure for such a debate (Swart, 2019). The analysis deliberately steps away from a focus on low-cost solutions and would, therefore, be useful alongside MAC curves and IAM results. A key asset is that the method is fully transparent: all data is in view and this provokes a discussion on the arguments supporting the Y factor scores, in particular when used interactively (Swart, 2019). The Y factor does not explicitly mention energy and climate policies but it fits to the policy process (Swart, 2019). The Y factor may inspire policies that, if effective, alter individual scores in specific regions or under specific conditions. Examples are economic policies that could affect costs and financing factors, rules and regulations that could affect multi-actor complexity factors, innovation policies that could affect factors related to physical interdependences and information policies that could affect behavioural factors. At the end of the day, we hope that such policies resolve key barriers hampering the abatement urgently needed for the Paris 1.5° goal to stay within reach.

CRediT authorship contribution statement

E.J.L. Chappin: Writing - original draft, has written the paper, developed the Y factor concept, has developed the preliminary set of definitions and a preliminary scoring, has improved the Y factor website, has developed the final Y factor definitions, and has supervised all the steps of the work by the other authors. M. Soana: Writing - review & editing, has performed the Y factor scoring as presented in the paper with literature review and has performed the validation by means of semi-structured interviews with sector experts, Writing - review & editing, has performed the Y factor scoring as presented in the paper with literature review and has performed the validation by means of semi-

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We acknowledge Andreas Ligtvoet on early discussions regarding the Y factor. We acknowledge Sofie van Zijl and Laurens Hesselink on their work on the McKinsey data and our discussions. We acknowledge Gosie Barzec (McKinsey) for supporting us by providing their model and data.

References

Anderson, K., Jewell, J., 2019. Debating the bedrock of climate-change mitigation scenarios. Nature 573, 348–349. https://doi.org/10.1038/d41586-019-02744-9.

Arensman, Carolien. 2018. Understanding Barriers to CO2 Abatement: the Y-Factor Applied (Msc thesis). Delft University of Technology.

Barthel, C., Busse, Maike, Ireyk, Wolfgang, Thomas, Stefan, 2006. Options and Potentials for Energy End-Use Efficiency and Energy Services (Project coordinator), With support from: Thomas Hanke, Gerhard Wohlfahrt, Lars Kirchner, Oliver Wagner, Natalia Przhevalskaya. Wuppertal Institute for Climate, Environment and Energy.

Bijker, W.E., Hughes, T.P., Pinch, T.J., 1987. The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. MIT Press, Cambridge, MA.

Blok, K., Worrall, E., Cuenlaere, R., Turkenburg, W., 1993. The cost effectiveness of CO2 emission reduction achieved by energy conservation. Energy Pol. 21, 656–667. https://doi.org/10.1016/0301-4215(93)90289-R.

Brujin, J.A.de, Herder, P.M., 2009. System and actor perspectives on sociotechnical systems. IEEE Trans. Syst. Man Cybern. Part -Syst. Hum. 39, 981–992.

Capros, P., Porousos, L., Fragos, P., Tsani, S., Boitier, B., Wagner, F., Sebastian, Busch, Resch, G., Biesis, M., Bollen, J., 2014. Description of models and scenarios used to assess European decarbonisation pathways. Energy Strategy Rev 2, 220–230. https://doi.org/10.1016/j.esr.2013.12.008.

Chappin, E.J.L., 2016. Complementing weaknesses in marginal abatement cost curves. In: 39th IAEE International Conference “Energy: Expectations and Uncertainty.

Dixit, A.K., Pindyck, R.S., 1994. Investment under Uncertainty. Princeton University Press, Princeton, N. J.

Edwards, N., 2011. Plausible mitigation targets. Nat. Clim. Change 1, 395–396. https://doi.org/10.1038/nclimate1207.

Eide, M.S., Longva, T., Hoffmann, P., Endresen, S.B., 2011. Future cost scenarios for reduction of ship CO2 emissions. Marit. Pol. Manag. 38, 11–37. https://doi.org/10.1080/03088839.2010.533711.

Eory, V., Pellerin, S., Carmona Garcia, G., Lehtonen, H., Licite, L., Mattila, H., Lund- Sorensen, T., Muldowney, J., Poploga, D., Strandmark, L., Schulte, R., 2018. Marginal abatement cost curves for agricultural climate policy: state-of-the-art, lessons learnt and future potential. J. Clean. Prod. 182, 705–716. https://doi.org/10.1016/j.jclepro.2018.01.252.

ESMAP, 2012. Planning for a Low Carbon Future: Lessons Learned from Seven Country Studies. Knowledge Series 011/12, Energy Sector Management Assistance Program. The World Bank.

Foxon, T., 2006. Bounded rationality and hierarchical complexity: two paths from Simon to ecological and evolutionary economics. Ecol. Complex. 3, 361–368.
Geels, F., 2002. Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Res. Pol. 31, 1257–1274.

Hekkert, M.P., Suurs, R.A.A., Negro, S.O., Kuhlmann, S., Smits, R.E.H.M., 2007. Functions of innovation systems: a new approach for analysing technological change. Technol. Forecast. Soc. Change 74, 413–432. https://doi.org/10.1016/j.technfore.2006.03.002.

Herder, P.M., Bouwmans, L., Dijkema, G.P.J., Stikkelman, R.M., Weijnen, M.P.C., 2008. Designing infrastructures using a complex systems perspective. J. Des. Res. 7, 17–34.

Hesselink, L., Chappin, E.J.L., 2019. Adoption of energy efficient technologies by households - barriers, policies and agent-based modelling studies. Renew. Sustain. Energy Rev. 99, 29–41.

Hughes, T.P., 1987. The evolution of large technological systems. In: Bijker, W.E., Hughes, T.P., Pinch, T.J. (Eds.), The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology. MIT Press, Cambridge, Mass, pp. 51–82.

Intergovernmental Panel on Climate Change, 2014. Climate Change 2014 Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. https://doi.org/10.1017/CBO9781107415416.

Jackson, T., 1991. Least-cost greenhouse planning supply curves for global warming abatement. Energy Pol. 19, 35–46. https://doi.org/10.1016/0301-4215(91)90075-Y.

Kesicki, F., Ekins, P., 2012. Marginal abatement cost curves: a call for caution. Clim. Pol. 12, 219–236. https://doi.org/10.1080/14693062.2011.582347.

Kesicki, F., Strachan, N., 2011. Marginal abatement cost (MAC) curves: confronting theory and practice. Environ. Sci. Pol. 14, 1195–1204. https://doi.org/10.1016/j.envsci.2011.08.004.

Loorbach, D., Kemp, R., 2005. Innovation Policy for the Dutch Energy Transition. Dutch Research Institute for Transitions (DRIFT).

Naué, T., Enkvist, P.-A., 2009. Pathways to a Low-Carbon Economy - Version 2 of the Global Greenhouse Gas Abatement Cost Curves. McKinsey.

Pachauri, R.K., Mayer, L., 2015. Intergovernmental Panel on climate change. In: Climate Change 2014: Synthesis Report. Intergovernmental Panel on Climate Change. Geneva, Switzerland.

Soana, Michele, 2018. Exposing the Complexity of GHG Reduction: Validation of a Multi-Criteria Emission Abatement Curve Built with the Y-Factor to Support Sustainable Energy Strategies (MSc Thesis). Delft University of Technology.

Taylor, S., 2012. The ranking of negative-cost emissions reduction measures. Energy Pol. 48, 430–438. https://doi.org/10.1016/j.enpol.2012.05.071.

Viebahn, P., Chappin, E.J.L., 2018. Scrutinising the gap between the expected and actual deployment of carbon capture and storage—a bibliometric analysis. Energies 11. https://doi.org/10.3390/en11092319.

Ward, D.J., 2014. The failure of marginal abatement cost curves in optimising a transition to a low carbon energy supply. Energy Pol. 73, 820–822. https://doi.org/10.1016/j.enpol.2014.03.008.

Weisbuch, G., Buskens, V., Vuong, L., 2008. Heterogeneity and increasing returns may drive socio-economic transitions. J. Comput. Math. Organ. Theory 14, 376–390.

Williamson, O.E., 1998. Transaction cost economics: how it works; where it is headed. Econ. Times 146, 23–58.