

Evaluating barriers to CO₂ abatement

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Abstract

The Marginal Abatement Cost Curve (MACC) implies that materialisation of CO₂ abatement options is only impeded by implementation costs. This disregards the underlying complexity as non-economic barriers have proven to be relevant. The Y-factor complements the MACC as it includes financial, multi-actor, technical and behavioural barriers. This research applied the Y-factor for the first time in expert interviews on a selection of abatement options. This resulted in generic lessons on barriers to CO₂ abatement as well as lessons specific to the Y-factor. Links between barriers are essential to understand complexity. Also, the perception of barriers from the view of the initiator of an abatement project is relevant for evaluation. Last, scoping abatement options with respect to geography, the initiating party and its physical boundaries is essential to gather specific information on barriers. The Y-factor provides a complete narrative of the materialisation barriers. It indicates where intervention may benefit materialisation and therefore offers possibilities for policy evaluation.

Keywords: CO₂ abatement option; barriers; materialisation; Marginal Abatement Cost Curve; energy transition

Are investment costs the only barrier to CO₂ abatement materialisation?

In 2009 McKinsey and Company published an overview of the cost and potential of a wide range of CO₂ abatement options with their publication of the Marginal Abatement Cost Curve (MACC) (Nauc ler & Enkvist, 2009). Abatement options are ordered in a curve with respect to their costs of materialisation per ton CO₂ emissions reduced. This curve implies to policy-makers that the costs are the only barrier to the realisation of CO₂ abatement options. However, are investment costs the only barrier to impede the materialisation of abatement options?

The options must be implemented in existing technical structures, the living environment of citizens and the current institutional setting of a country or area. This can be illustrated by the realisation of a wind

park. When built, the wind park has to be connected to existing technological structures (the electricity network). This intermittent energy source demands additional attention for the network operator. The landscape changes when a wind park is built, which can lead to opposition from local citizens. Permits for the wind park have to be issued by different authorities, the procedures may have long durations. Some uncertainty may also be present on the pay-back period, as the electricity prices are uncertain in the future.

Introducing the Y-factor

Chappin developed the Y-factor, to provide more insight into barriers that may impede materialisation of CO₂ abatement options (Chappin, 2016). With this research method he aimed to complement the analysis of the MACC. He uses four categories of barriers: costs and financing, multi-actor complexity, physical interdependencies and behaviour.

These categories consist of three or four barriers each which adds up to thirteen barriers in total. In appendix I these barriers and their definitions are presented. In this paper, the Y-factor was used as a research method to increase the understanding of the barriers to materialisation of CO₂ abatement.

Complementing the weaknesses of the MACC?

With the Y-factor, Chappin intends to complement the weaknesses of the MACC identified by Kesicki and Strachan (2011). Some of the weaknesses are lack of transparency on assumptions and lack of showing complexity. Several other weaknesses relate to cost definitions, discount rates and showing uncertainty ranges for costs. As the Y-factor does not quantify costs, these last weaknesses related to cost quantification cannot be complemented nor improved by the Y-factor.

The Y-factor shows improvement with regard to transparency in scoring as it uses three scoring options per barrier. This contributes to the understanding of the allocated score. The complexity of the realisation of abatement options is shown by the range of barriers. This can aid a researcher to gather a system's view on the matters that are relevant for the abatement option under investigation.

Structure paper

The remainder of this paper shows the results of the analysis of expert interviews where the Y-factor was applied. First two abatement

options are described. This is followed by various more general insights on barriers to CO₂ abatement. In the discussion a reflection is presented on the comparison of abatement options. Last, the conclusion and future research options are presented.

Method

To increase the understanding of barriers to abatement, the Y-factor was applied in expert interviews. The investigated options were: Carbon Capture Storage, Biofuels, Insulation and Geothermal energy. These options are part of different sectors namely industry, transport the built environment, and energy. All options have been scoped geographically to the Netherlands. The last two options will be further elaborated in this paper. Three to four expert interviews per abatement option have been performed. The interview reports supporting the analysis can be found in appendix B.1 and B.4 of (Arensman, 2018)¹.

Results: Insulation and geothermal energy discussed

The complexity of barriers to materialisation is illustrated by presenting the summaries of the abatement options insulation and geothermal energy. The summarised interview results are structured by the Y-factor barriers. The Y-factor scores are presented in figure 1. The thirteen barriers of the Y-factor are presented on the x-axis of this figure, definitions can be found in appendix I.

¹ This thesis is available in the repository of the Technical University of Delft after June 1st 2018.

<https://repository.tudelft.nl/islandora/search/?collection=education>

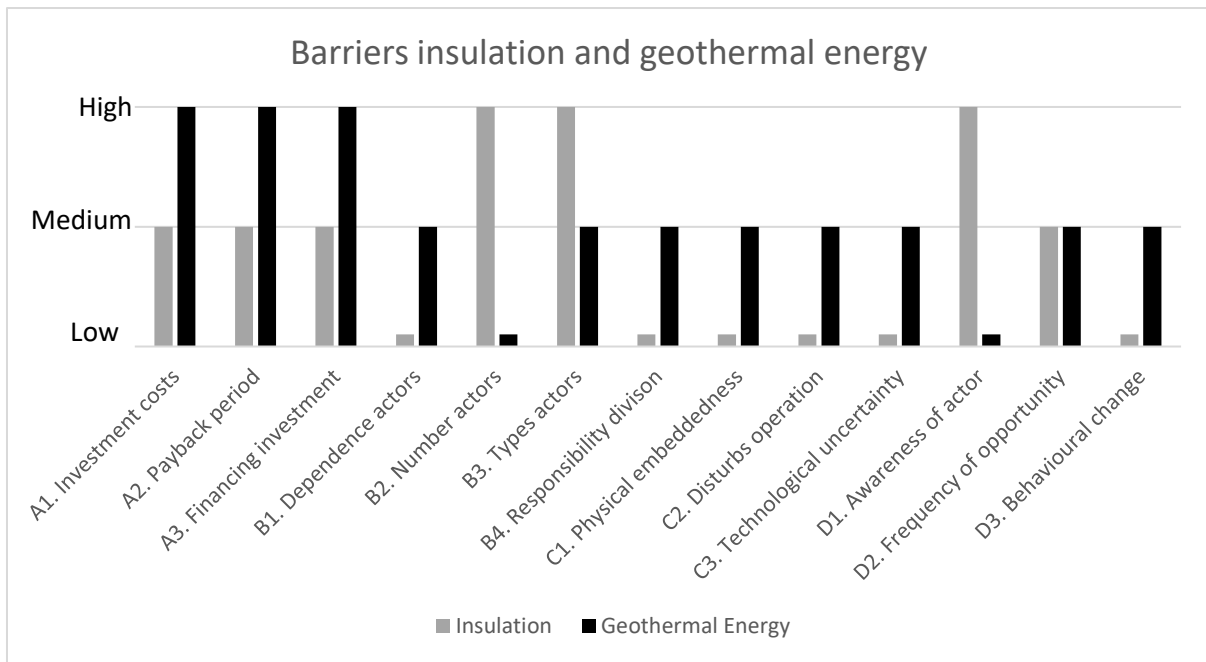


Figure 1: Results Y-factor scores Insulation and Geothermal Energy based on (Arensman, 2018)

Insulation

The scope of the abatement option ‘insulation’ is private home owners of houses with a cavity wall and where floor insulation can be added in the crawl space. The costs and financing are a relevant barrier to insulation. Investment costs are an important decision-factor for households, although it is a surmountable barrier (A1). Households have difficulties with estimating if they will earn back the investment during the time they own the house (A2). They might move before the payback period of five to twelve years. In the Netherlands, subsidies are present for insulation measures in several municipalities, although it is not easy to get a clear overview of the options (A3).

Home owners can decide to insulate without depending much on other parties, only a constructor must be contacted to execute the works (B1). The decision to insulate must be taken by many households in the Netherlands to result in a significant CO₂ emission reduction (B2). Diverse motives drive this decision (e.g. comfort or financially driven). The household’s financial reserves and type of houses also differ (B3).

Households do not always feel responsible to reduce their energy usage by insulating their house (B4). Taking the actual step to install insulation is postponed due to various reasons.

The barriers in the category ‘physical interdependencies’ all show low scores, these do therefore not seem to be the largest hurdle for a household. Adding insulation does not visually change the house of the home owner (when a cavity wall and crawl space are present) (C1). The disturbance of the works is also low, as the duration is short (one or two days). Many households do perceive this disturbance as a barrier due to their lack of knowledge on the exact works (C2). The technological uncertainty on insulation materials is low, as materials have been used for decades (C3).

The lack of awareness is an important reason why home owners procrastinate taking insulation measures or do not take them. Many home owners do not know what the volume of heat that flows from their homes, as it is not visible. For a group of home owners, it also not evident what steps are necessary for the installation of insulation

(D1). Households often take action on natural moments, for instance in combination with other home improvements or when they move to another house (D2). After insulating, the changes to day-to-day behaviour are limited. Only some changes have to be made with respect to ventilation of the house (D3).

Geothermal energy

The demarcation of the abatement option ‘geothermal energy’ is projects where horticulturists are project initiators that change to geothermal energy for heating their greenhouses. The main barriers for project initiators are the investment costs (A1) (several millions of euros) and the pay-back period (A2) of this investment (between ten and fifteen years). A subsidy on the production of sustainable sources (SDE+ in the Netherlands) is essential to reduce the pay-back period to this duration and therewith build a viable business case. Project costs are often borne by joint-ventures of horticulturists. Banks that offer loans to these joint-ventures perceive the geological risk as most significant. The local geology determines the production capacity of the source.

The dependence on other parties (B1) is large during the preparation phase of geothermal energy projects. Loans have to be acquired from banks, permits from different authorities have to be collected, research on geology must be performed to apply for these permits and the approval from local residents should be obtained. The number of parties involved is limited in geothermal energy projects initiated by horticulturists (B2). No actions from citizens are needed to start a project for horticultural purposes. The diversity of interests (B3) amongst involved actors is a relevant issue. Some duality of interests is also found within organisations. An example is the Ministry of Economic Affairs and Climate. This party decides on the

approval of permits according to regulations, while at the same time aims to stimulate the growth of sustainable energy sources in the Netherlands. Some indistinctness of responsibility (B4) is noted for the supervisory authority. As the geothermal energy sector is young in the Netherlands, this party often provides advice to projects in development although this may conflict with their supervisory role.

The visual change to the environment of a geological source is limited (C1). A small building that houses a heat exchange installation does not stand out in a horticultural environment. The structure in the subsurface is not observable in the landscape. The disturbance of the works is limited (C2). Local residents may be bothered by nuisance and some logistical challenges may arise on the terrain of the horticulturists. Technological uncertainty (C3) results from geological uncertainty. The production quantity of the source depends on what is found in the underground.

The option of geothermal energy is well-known by horticulturists in the Netherlands as an alternative to heating with fossil fuels (D1). Geological research is needed to see if the subsurface is suitable for this technology. Location-dependency is thus an important determinant for the number of opportunities of this technology (D2). Occasions to shift to this heating source occur when replacement of the heat source is needed. Next to this, financial reserves must be present as well to be able to start a project. After a geothermal energy source is installed, its geothermal operator has to perform some measurements and maintenance to the source. This does however not impact its day-to-day job substantially (D3).

Insight into barriers to CO₂ abatement

The summarised interviews prove that Y-factor provides insight into barriers to CO₂

abatement. These findings are relevant to both illustrating the value of the Y-factor as well as increasing the more general understanding of abatement barriers. A number of other insights from the analysis of the expert interviews are discussed in more detail in this section.

Large heterogeneous group of initiators

From the analysis of the barriers to insulation, a more general conclusion can be drawn. This abatement option can be characterised by its large number of initiators (households). The heterogeneity of this group is large as these may have different incomes, types of houses, motivations (e.g. financially driven or comfort-driven). It is a challenging task to present information in such a way that it appeals to this group and can draw their attention to this topic. This same challenge is also relevant to other abatement options that demand action from households as it was observed for biofuels as well.

Capital-intensive abatement options

From the analysis of the barriers to the realisation of geothermal energy projects, generic insights on capital-intensive abatement options can be concluded. The high investment costs are a major barrier for geothermal energy projects. It is therefore important to reduce risks that influence these investment costs as much as possible. This stimulates the initiator of the project to take the investment decision. Risks of geothermal energy projects were mostly observed in the dependence on other authorities for permits and the geological uncertainty. This last one is the most important determinant of the production capacity of the geothermal source. This production capacity strongly affects the pay-back period of the investment.

Robustness of barriers

The barriers proved to be stable for the researched abatement options over the past decade in the Netherlands. For example, no large improvements in the payback period were detected. However, major cost cuts have been observed in the past decade for wind energy and solar energy (International Renewable Energy Agency [IRENA], 2018). The stable scores do nevertheless indicate that interventions to reduce barriers of the researched abatement options have not yet led to a 'break-through'.

Links between barriers

Another insight relates to the links between barriers. The relations indicate the complexity of reducing barriers. Two types of links have been noted. The first type is a 'cause-effect' link. An example is the dependence on other actors for geothermal energy. The approval of the large number of permits and their long procedures (B1) are a risk for banks that finance investment (A3) for geothermal energy projects. The second type of link is the 'common couple'. This link is observed when some high scores often occur together. An example is a high score on the number of actors (B2) and a high score on D1 (outside thinking scope of actor). This couple was observed for both insulation and biofuels. Households are the initiators to install insulation, however they are not thinking about taking action on both topics as these are far from their daily routine. They lack knowledge on the amount of heat that is wasted without insulation and sometimes also lack knowledge on which steps to take to install insulation.

Interventions to reduce barriers

In the expert interviews, an inventory of interventions for the abatement options was made, comprised of current and potential interventions. These interventions could be linked to one or more barriers that they could reduce. This offers possibilities for applying the Y-factor for policy evaluation purposes. Some of the interventions aimed at influencing households are labour-intensive, for example door-to-door advice. This makes

them difficult to scale up to reach all Dutch households. Scalability is an important factor when evaluating interventions that must have a large impact.

It was also concluded that an intervention does not always have the same nature as the barrier it aims to affect. The cause for the barrier should be known when an intervention is designed. This is illustrated by an example from insulation. Many households expect significant disturbance from the installation of insulation. This is however not always an informed expectation. A lack of knowledge causes this perception of a high barrier. Hence, an intervention where information is spread on the disturbance can reduce this 'technical' barrier.

Scoping of abatement options

The interviewees on one abatement option provided different scores for several barriers. The difference of reference frame was the largest source of uncertainty that caused this variance. To reduce this uncertainty, demarcation of abatement options with respect to three aspects are proposed.

First, geographical scoping (preferably on a country-level) is needed as this determines the regulations and potential subsidy schemes. The presence of subsidy can make it possible to build a viable business case for an abatement project. The geographical scope also influences the 'physical' frequency of opportunity resulting from, for instance, the geological structure in a country or its density of population. The seismic risk should for example be low for geothermal energy projects.

The focus on the initiator determines which 'actor group' is evaluated. Insulation in a private house is a different case than insulation measures initiated by a housing cooperation or an association of owners in an apartment building. These last initiators are less independent in their decision-making and have a different available budget compared to private home-owners.

Physical scoping is needed as this determines costs, technological complexity and also affects the actor group. A geothermal energy project in a horticultural

environment has limited users of the heat, a small heat network might be needed. However, a geothermal energy project in the built environment (neighbourhood) has a larger number of customers for heat resulting in the need for a more extensive (and more expensive) heat distribution network.

Hence, different 'types' of projects of the same abatement technology show substantial differences in the presence of barriers. This is not only relevant to the use of the Y-factor, but also to understanding the realisation of abatement options on a more general level. As barriers can differ for different demarcations of the same abatement technology, this indicates the need for different interventions. It is essential to specify the scope well when discussing an abatement option to prevent misunderstanding.

Public acceptance

In half of the expert interviews the additional barrier of opposing interests on the development of abatement projects was mentioned. The summarising concept of this topic is known as 'public acceptance' (or the lack of it). This can be defined as 'the favourable reception of an abatement option by a community'. The community can be a local community (regional or neighbourhood level) but can also refer to the national level. To evaluate this topic, the adequate scale of the community should be chosen. One way to choose this scale is to take into account the scale of the abatement option. Devine-Wright (2007) uses the following scales for the implementation of renewable energy technology that can be helpful in defining this scale:

*“- micro (at single building or household level);
- meso (at the local, community or town level) and
- macro (at large scale 'power station' level)”*
(Devine-Wright, 2007, p. 8).

Specifically for the Y-factor: It is recommended to change the definition of barrier B3 (types of actors) in the Y-factor show the relevance of this barrier more explicitly in this method.

Barrier perception

The Y-factor evaluates categories with mainly qualitative barriers (the pay-back period is the only exception). To provide proof for the selected 'qualitative' scores it is essential to provide arguments or a narrative based on expert interviews or a literature study. This is comparable to the assumptions that have to be reported when using quantitative results in research. The supporting story can also show the real cause of a barrier and is therewith vital to understand the complexity of materialisation.

The supporting story proved to be essential in understanding barriers households perceive for the installation of insulation. With perception it is meant that a barrier is judged as impeding, but when objectively evaluating it this obstacle would not be expected. Translated to the Y-factor, this means a high barrier score is given due to the perception. However, based on facts the barrier score would be low.

This can be illustrated by the disturbance of the installation of insulation. This is perceived as a barrier by home-owners and a reason to postpone an insulation project. In the expert interviews it however was noted that households often lack knowledge on the duration of and mess caused by these works.

The presence of a barrier is evaluated from the initiator's perspective. If this initiator perceives this barrier, then it could be viewed as relevant, since this barrier blocks the materialisation of the abatement option.

Discussion

Comparing abatement options

The notion that barriers are evaluated from the initiator's perspective is relevant when comparing abatement options by using the Y-factor. The investment costs should, for example, be related to the initiating party. A company can finance larger investments than a single household. A high score on this barrier can be supported by a rather different cost figure.

Next, one should also be aware that

not all barriers with the same score have a similar 'level of difficulty' to reduce. This results from the difference in nature of the barriers (e.g. financial, multi-actor, technical or behavioural). The supporting stories can indicate the cause for the barrier and therewith provide information on the difficulty to overcome the barrier and the type of intervention needed. Hence, one should be cautious in comparing Y-factor scores one-on-one within and between abatement options. Supporting stories can provide more information on the barrier causes.

Next to comparing abatement options by using the Y-factor, a more generic remark on studying one abatement 'technology' is also of relevance. A geothermal energy project in a horticultural environment is characterised by different barriers than a project in the built environment. The higher number of heat consumers and the need for a heat distribution network ask for a different focus in stimulating these developments. One should thus be careful in drawing conclusions on one abatement option in a generic sense. Scoping is essential for specific results.

Implications for the policy arena

The aforementioned points of discussion are relevant to the use of the Y-factor in the policy arena. The Y-factor should be seen as a method to gather information on the barriers, presented in both scores as well as a supporting story. To come to a policy advice, other information sources should be incorporated in the decision-making process.

First, the technological potential of the abatement options in one sector should be compared. The Y-factor barriers (both high and medium scores) can indicate where additional interventions may be beneficial. The information on the allocated budget for interventions should be combined with the most relevant interventions. From this information a realistic potential can be estimated. For this step, a translation of mostly qualitative barriers to quantitative data should be made. This data is the effect of the proposed interventions on materialisation,

which is the realistic potential. The aforementioned information can be the basis for a political decision.

Conclusion

In this research, the Y-factor, developed by Chappin (2016), was applied in expert interviews to increase the understanding of barriers to CO₂ abatement. The appliance of this method provided a range of insights.

The barriers were illustrated in the interview summaries on insulation and geothermal energy. This shows for these specific abatement options what the barriers entail. When abatement options must be initiated by households, the main challenge is to appeal to and convince a heterogeneous group of actors. For capital-intensive abatement options, the uncertainty around the investment should be reduced as much as possible to stimulate materialisation.

When investigating barriers to abatement, one should be aware that different demarcations of the same abatement 'technology' can show different barriers (geothermal energy in a horticultural environment differs from applying this technology in the built environment). Therefore, it is recommended to scope with respect to geography, the initiating party and physical boundaries of abatement projects to gather specific information.

The barriers to materialisation are perceived from the perspective of the project initiator. Hence, the perception of the initiator on a barrier is as relevant as its 'objective' presence. The barriers should thus be related to the initiator's perception but also to for example its available budget. Therefore, one should be cautious when comparing barrier scores between abatement options.

Finally, some additional insights are presented on barrier characteristics and how these can be used in policy evaluation. Links between barriers have been observed and show the complexity of materialisation. Barriers proved to be robust over the past

decade for the reviewed options. High barrier scores of the Y-factor could be viewed as signposts to the focus of interventions. The narrative that supports these barrier scores indicates the barrier cause and provides input for the design of a suitable intervention to reduce this barrier. Hence, the Y-factor results can provide input for policy evaluation.

Future research

Future research on understanding barriers to CO₂ abatement can have different directions. First, exploring how the Y-factor can be used for policy evaluation purposes by linking current and potential interventions to Y-factor barriers. Second, abatement options within one sector can be compared to see if similar barriers are observed. An intervention strategy on sector level could potentially be developed. Third, a design could be developed to weigh the importance of barriers in abatement options. This can show where most attention is needed to reduce barriers to materialisation of an abatement option.

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Appendix I: Y-factor definitions

The definitions in table 1 were used to by Chappin (2016) to construct his reordering of the fifty cheapest abatement options of the MACC of McKinsey. The element 'skills' in B3 was added after literature research in (Arensman, 2018). The values 0, 1 and 2 that were used by Chappin are replaced by low, medium and high.

Table 1 Y-factor including definitions

A. Costs and financing	Low	Medium	High
A.1 Investment cost required	Absent	Medium	Large
Degree to which the investment in an abatement measure is significant			
A.2 Expected pay-back time at 0 euro/ton	< 5 years	5-12 years	>12 years
Expected time required to earn back the investment for an abatement measure			
A.3 Difficulty in financing investment	None	Medium	Large
The degree to which it is difficult to finance the abatement or attract appropriate financial means			
B. Multi-actor complexity	Low	Medium	High
B.1 Dependence on other actors	None	Few	Many
Degree of dependence on actions of other actors to successfully implement and execute the abatement measure			
B.2 Number of actors	Few	Many	Millions
Number of actors that are required to take action to realise the abatement measure			
B.3 Types of actors involved	Few	Medium	Many
Degree of diversity of interests, values, roles, skills and expectations of the actors involved			
B.4 Responsibility unclear	Clear	Slightly	Unclear
The extent to which it is clear which actor has the responsibility for the abatement measure			
C. Physical interdependencies	Low	Medium	High
C.1 Physical embeddedness	No	Medium	Strongly
Degree to which the abatement measure requires physical changes to the environment it is placed in			
C.2 Disturbs regular operation	No	Slightly	Strongly
Degree (duration, intensity) to which status quo/regular operation is disrupted to successfully apply the abatement measure			
C.3 Technology uncertainty	Fully proven	Small	Large
Degree to which the technological performance of the abatement measure is uncertain			
D. Behaviour	Low	Medium	High
D.1 Outside of thinking scope of actor	No	Partly related	Outside scope
Degree of awareness of the parties responsible for the abatement measure			
D.2 Frequency of opportunity	Often	Medium	Rarely
Number of opportunities for the responsible party to realise the abatement measure			
D.3 Requires change in behaviour	No	Slight	Severe
Degree to which the actors involved need to change their day to day behaviour			