# CONTRIBUTION TO CLIMATE CHANGE

*October 2021*

*True pricing method for agri-food products*

**Contribution to climate change**

Impact-specific module for true price assessment

True pricing method for agri-food products

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[4] For more information on the *PPS True and Fair Price for Sustainable Products*, please refer to https://www.wur.nl/nl/project/Echte-en-eerlijke-prijs-voor-duurzame-producten.htm

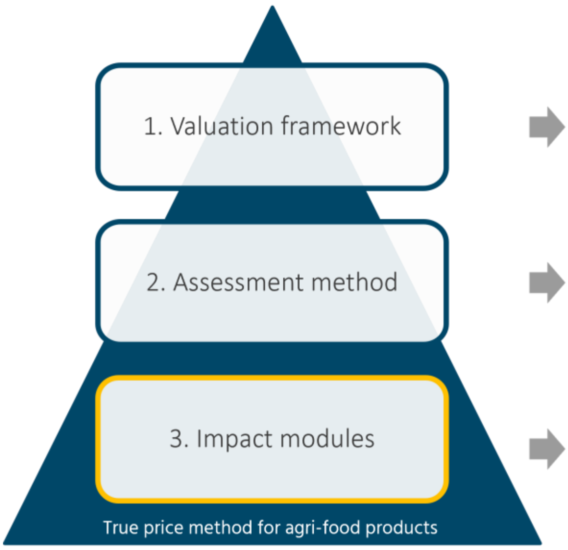
# Relation to other components of the true price methodology for agri-food products

*This **Contribution to climate change - Impact-specific module for true price assessment** was developed by True Price and Wageningen Economic Research within the PPS True and Fair Price for Sustainable Products.*

*This document contains the key methodological aspects to measure and value one impact of agri-food products and value chains: contribution to climate change.*

*This impact-specific module is complemented by five other **Natural capital modules** and seven **Social and human capital modules**. The other natural capital modules are: 1) Soil degradation; 2) Land use, land use change, biodiversity and ecosystem services; 3) Air, soil and water pollution; 4) Scarce water use; 5) Fossil fuel and other non-renewable material depletion. These impact-specific modules are preceded by the **Valuation framework for true pricing of agri-food products**, which contains the theoretical framework, normative foundations and valuation guidelines, and the **Assessment Method for True Pricing of Agri-Food products**, which contains modelling guidance and requirements for scoping, data and reporting (Figure 1).*

*Together, these documents present a method that can be used for true pricing of agri-food products, and potentially other products as well.*




| Content | Audience |
|---|---|
| Theoretical framework, normative foundations, definitions and valuation guidelines based on the True Price principles | Experts & method developers |
| Steps and requirements for implementation (completeness, accuracy, data, reporting, …) | Experts & practitioners |
| Definitions, footprint indicators, monetization factors and data guidelines for specific impacts (e.g. climate change, health & safety, water use …) | Experts & practitioners |

**Figure 1: Components of the true price methodology for agri-food products. This document is one of the impact modules.**

# Table of Contents

# 1. Introduction

This document provides a method module for the assessment of the true price of an agricultural or horticultural product, within the public-private partnership 'Echte en Eerlijke Prijs'. It contains the key methodological aspects to measure and value one impact of agri-food products and value chains: contribution to climate change.

This module must be used together with **The True Pricing Assessment Method for Agri-food Products** (Galgani et al, 2021a). As for other impacts in true pricing, this methodology is compatible with Life Cycle Assessment (LCA).

This module is organised as follows: Section 2 provides the definition on contribution to climate change. Section 3 provides background information and the rationale for including this impact as part of the true price. Section 4 offers guidance for scoping and determining materiality within a true price assessment. Section 5 presents the footprint indicator of the impact and Section 6 contains the modelling approach. Section 7 provides the monetisation approach. Finally, Section 8, provides an overview of key items for further research, as well the limitations of the research. In addition, annexes with additional information and a glossary of key terms are provided at the end of the document.

# 2. Definition

The impact contribution to climate change is defined as the rise of the global mean temperature caused by increased emissions of greenhouse gases (GHG) due to anthropogenic activities (Johnson et al., 2007). The impact is measured by the increase in greenhouse gases (GHG) and includes carbon dioxide, methane, and nitrous oxide, which are primary greenhouse gasses, as well as other greenhouse gases identified by the Kyoto protocol such as sulphur hexafluoride, hydrofluorocarbons, and perfluorocarbons (Metz et al., 2007). Emissions of GHG increase their atmospheric concentration (ppb), which in turn increases the radiative forcing capacity and consequently increases the global mean temperature (Metz et al., 2007).

The climate system has been subject to unprecedented changes over the past century, the main cause of which is human-induced $CO_2$ emissions (Allen et al., 2018). When anthropogenic activities increasingly disrupt climatological patterns, this has long-lasting impacts on human- and natural environments. According to the IPCC, global warming increases climate-related risk associated with enduring and irreversible changes of natural and human systems (Allen et al., 2018). Climate-related risks include extreme warm temperatures; increases in frequency, intensity, and amount of heavy precipitation; ocean acidification; and droughts and precipitation deficits. Ultimately climate change results in economic damage, political instability due to hunger and freshwater scarcity (Raleigh & Urdal, 2007), damage to human health – e.g., malnutrition and increased risk of diseases, such as malaria and diarrhoea – and damage to ecosystems (Huijbregts et al., 2017).

# 3. Background and rationale for including as part of the true price

This section defines why contribution to climate change should be included in the assessment of the true price of a product. It builds on the principles presented in **The Valuation Framework for true price assessment of agri-food product** (Galgani et al., 2021b), and covers two aspects: the link to basic rights of people, and the associated responsibility for economic actors.

The true price method takes a rights-based approach[5]. In the context of true pricing, every (unsustainable) impact relates to a limitation of rights. Contribution to climate change violates *the right to a safe, clean, healthy and sustainable environment* of current and future generations. This is linked to ambitions stated in multiple United Nations declarations, conventions and documents (True Price Foundation, 2020), such as the Declaration of the United Nations Conference on the Human Environment (UN, 1972), Our Common Future (Brundtland, 1987), the Kyoto Protocol (UN, 1998), the Sustainable Development Goals (UN, 2015a), the Paris Agreement (on Climate Change) (UN, 2015b), and the Framework Principles on Human Rights and the Environment (UN Human Rights Special Procedures, 2018). For an overview of how *the right to a safe, clean, healthy, and sustainable environment* is represented in various international conventions with relation to climate change, refer to Annex B.

In the rights-based approach, the true price is higher than the price of a product whenever economic actors do not meet their responsibility to avoid external costs[6]. At the moment, all economic actors together emit more than is required to limit climate change to safe levels (e.g., meeting the Paris agreement). According to the Consultative Group on International Agricultural Research, '*reducing agriculture's carbon footprint is central to limiting climate change*' (Gilbert, 2012). Specifically for food production, the global estimate of all GHG emissions is around 8.5 -13.7 Gt of $CO_2$ equivalent per year (Willet et al., 2019, pp 463), while scientific targets for a safe operating space for sustainable food production is an estimated range of 4.7 - 5.4 Gt of $CO_2$ equivalent per year (Willet et al., 2019, Table 2).

It is a complicated exercise to translate collective to individual responsibility. There are no generally accepted and easily applicable ways to give GHG-quota to organizations or individuals, let alone to products. Consistent with the approach in the other modules all GHG emissions are regarded as external costs as opposed to only those above a certain quota. Nevertheless, it may be valuable to investigate which (regulatory) frameworks or methods can be used to determine a certain allowance of GHG emissions at the product level.

# 4. Guidance for the scoping phase of a true price assessment

In a typical scoping phase of a true price assessment, the researcher should identify all relevant processes in the life cycle of the product (or steps in its value chain). This involves assessing which intermediate products are produced and what inputs are required. After that, it should be determined which impact must be quantified for each process in the life cycle – a so-called materiality assessment - by identifying all relevant processes that are expected to contribute more significantly to the total impact. This helps the analysis as it focusses attention on these processes in subsequent steps. This process should be done following the steps and requirements laid out in the **True Pricing Assessment Method for Agri-food Products** *(*Galgani et al, 2021a).

A list of relevant processes that are expected to contribute materially to GHG emissions are presented in Table 1 (this list is not considered exhaustive).

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[5] In this context, a sustainable society means a society in which everyone's rights are respected, including those of future generations. In addition, a sustainable product is a product for which no rights are violated. See The Valuation framework for true price assessment of agri-food products (Galgani et al, 2021b) and Principles of true pricing (True Price Foundation, 2020).

[6] This is argued in the *Principles of True Pricing*, based on the Principles of Business and Human Rights (UN, 2011) and the OECD Guidelines for Multinational organizations (OECD, 2011).

**Table 1: Some high materiality processes related to contribution to climate change and associated emission types**

| Process | Emissions |
|---|---|
| Keeping cattle | Mainly for methane ($CH_4$) emissions |
| Using agricultural chemicals such as chemical fertilizers and pesticides | Mainly for nitrous oxide ($N_2O$) emissions from application and $CO_2$ and other greenhouse gas emissions during manufacturing of the chemicals |
| Transport and use of machineries on the land | Mainly for $CO_2$ emissions from fuel combustion |
| Requiring land, whether recently converted or not | Mainly for $CO_2$ emissions from land use change |
| Using energy intensive processes for other purposes such as heated greenhouses, storage, refrigeration, and food processing | Mainly for $CO_2$ emissions from energy usage |

# 5. Footprint indicator

The impact contribution to climate change is measured through one footprint indicator, greenhouse gas (GHG) emission. The Global Warming Potential (GWP) approach [7] allows to convert various types of GHG emissions in a single unit, kg $CO_2$-eq.

**Table 2: Overview of footprint indicator modelling approach and associated source**

| Footprint indicator | Unit | Modelling approach | Source model |
|---|---|---|---|
| GHG emission | kg $CO_2$ equivalent | Global Warming Potential (GWP) | Bern Model (Metz et al., 2007) |

The GWP factors are time-frame specific. The choice of time frame affects the eventual impact of contribution to climate change: GHGs have different atmospheric lifetimes, resulting in time-frame dependent modelling parameters (Joos et al., 2013). 20-, 100- and 500-year time frames are often used. In adherence to both PEF and ReCiPe recommendations, the Bern model with a 100-year time frame is selected (IPCC, 2007 as cited in European Commission, 2013; Huijbregts et al., 2017). This time frame corresponds to the Hierarchist perspective of ReCiPe's midpoint characterisation factors. Moreover, the Bern model is used by PEF, which takes into account considerations from similar, widely recognised product environmental accounting methods and guidance documents.

# 6. Modelling approach

This chapter explains the suggested modelling approach for contribution to climate change in two steps. First, it lays out the quantification model. Second, it discusses data quality requirements and possible

[7] The GWP approach expresses the amount of additional radiative forcing integrated over a certain timeframe caused by an emission of 1 kg of GHG, equivalent to the additional radiative forcing integrated over that same period caused by the release of 1 kg of $CO_2$. The amount of radiative forcing integrated over time caused by the emission of 1 kg of GHG is called the Absolute Global Warming Potential (AGWP) and is expressed in the unit W m-2 yr. kg-1. The modelling parameter of any GHG (x) and any time frame (TF) can then be calculated as follows: GWPx,TF= (AGWPx,TF)/(AGWPCO2,TF) (Huijbregts et al., 2017).

sources for secondary process data. This modelling approach should be applied within the steps of the **True Price Assessment Method for Agri-Food Products** (Galgani et al, 2021a).

## 6.1. Quantification model

The generic formula for quantifying contribution to climate change for one specific process in the life cycle of an agricultural or horticultural product is presented below.

(1) $$I = \sum_i e_i CF_i$$

Where $I$ is the footprint indicator in kg $CO_2$-eq, $e_i$ is the emission type in kg, and $CF_i$ is the characterisation factor, representing GWP, or how much an emission type $e_i$ contributes to climate change in kg $CO_2$-eq/kg. Mid-point characterisation factors in the ReCiPe life cycle assessment methodology should be used (Huijbregts et al., 2017, p 29 -35, hierarchical method), which is consistent with the PEF method (European Commission, 2013). All GHG presented in Section 2 are included in the true price method, although the main greenhouse gases relevant in the agri-food sector are $CO_2$, fossil $CH_4$, biogenic $CH_4$ and $N_2O$ (Johnson et al. 2007); their GWP factors are 1, 36, 34, and 298, respectively[8].
In practice this approach has three steps:

1) Quantify all emission types that contribute to climate change; after this step, all the emissions are listed and quantified in kg. This corresponds to the life cycle inventory (LCI) in LCA.
2) Multiply each by a set of factors that indicates the contribution of that pollutant to GHG emissions e.g., 1 kg of $NO_2$ corresponds to 298 kg $CO_2$-eq. After this step, all emissions that contribute to this impact are expressed in kg $CO_2$-eq. In LCA this is called characterisation and the factors used are called characterisation factors.
3) Quantify GHG emission, by summing all emission types that contribute to that indicator. In LCA this and the previous step together are called life cycle impact assessment (LCIA).

## 6.2. Data requirements

Quantification of the emissions of these and other greenhouse gases from agricultural processes and agricultural value chains, entails collecting data describing GHG emissions in the relevant value chain steps. In practice, agricultural businesses will not have this kind of data, and emissions will have to be modelled based on other process data, such as the use of inputs (fertiliser, fuel, pesticides), herd sizes and herd diet, soil management practices, transport distances, electricity use, and more.

Several options are available for data collection:

1) Rely on published Life Cycle Assessment (LCA) or carbon footprint results of the considered product, of specific steps in the supply chain, or of specific inputs. These results could either be emissions of separate GHG or the aggregate in kg $CO_2$-eq. However, one must analyse carefully to what extent the methodology used is suitable.
2) Make use of data in LCA databases such as Eco-invent, Agri-footprint, Agribalyse, World Food Lifecycle Database, RIVM voedseldatabase and other databases.
3) Use an established model and methodology to calculate GHG emissions. Some models have been proposed by EMEP/EEA air pollutant emission inventory guidebook (EEA, 2019), the Hortifootprint

[8] In comparison, the GWP factors for a 20-year time frame are 1, 85, 84, and 264 respectively (Huijbregts et al., 2017, p 29).

Category Rules (Helmes et al., 2020), the Methodology for estimating emissions from agriculture in the Netherlands, by Wageningen UR (Vonk et al., 2016). One of these models can be chosen. These methods are generally consistent with each other. General frameworks have been proposed in literature and by IPCC, adopting a tiered method (Goglio et al., 2017; Goglio et al., 2015; Ogle et al., 2019a; Ogle et al., 2019b).

# 7. Monetisation

This section discusses valuation of GHG emissions that contribute to climate change. The monetisation factor is a marginal abatement cost, based on a meta-analysis (Kuik et al., 2009). The section starts discussing why marginal abatement is suitable, then argues why Kuik et al. has been selected.

## 7.1. Monetisation approach

The remediation philosophy of true pricing states that harm should always be restored/prevented, if that is technically feasible, where the (potential) harm is severe. The harm in this case is the actual manifestation of climate change that might occur if GHG emissions are not limited, that is linked to economic damage, damage to human health and ecosystem deterioration (Huijbregts et al., 2017). Research indicates that the Earth has already transgressed the planetary boundary. It is now approaching several Earth system thresholds (see e.g., Stockholm Resilience Centre, n.d.; Robèrt et al., 2013), implying that current emissions lead to potential long-term damage. As a result, the (potential) harm is assessed as severe.

Marginal abatement costs reflect the costs to prevent the last tonne of $CO_2$ from being emitted once the target is reached. This is an approximation of what the price of emission rights in a reasonably-well functioning market would reach, if emissions caps would be in line with the goal.

Kuik et al. (2009) provide a meta-analysis of marginal abatement costs of carbon and derive a range of values from that. The suggested monetisation value is the abatement cost for the 2 degrees global warming target in the long term, corresponding to a 450-ppm stabilisation target. This is in line with the Paris Agreement (UN, 2015b) that was negotiated and signed later.

Alternatives to the marginal abatement cost would be the market price of carbon and the Social Cost of Carbon. Annex A discusses why these alternatives have not been selected.

## 7.2. Monetisation factors

The suggested monetisation factor, presented in Table 3, is 0.152 $EUR_{2020}$/kg $CO_2$-eq. This is calculated from the original value in Kuik et al. of 129 EUR /tCO2 in 2025, expressed in fixed Euros with price level 2005. Two adaptations were made: firstly, the value was expressed for 2025 in Euros at the price level of 2025 using actual inflation (2005-2018) and forecasted inflation (2019-2025). Secondly, the value was extrapolated to the value of 2020 using Hotelling's rule with a discount rate of 3.5% as also recommended by Kuik et al (2009). It is a standard assumption in the literature on the economics of climate, that when only a fixed amount of GHG's can be emitted till infinity, that the price has to rise with the discount rate. For most other emissions the total emissions are not fixed, and therefore no price increase has to be expected. The resulting value is also in line with the central value in the environmental shadow prices by CE Delft (de Bruyn et al., 2017, p 109). See Annex A for a brief discussion about Hotelling's rule. The different monetisation factors for the years 2019 -2023 are presented in Table 3 below.

**Table 3: Monetisation factor for contribution to climate change in EUR/kg $CO_2$-eq.**

| Year | Monetisation factor |
|---|---|
| 2019 | 0.148 |
| 2020 | 0.152 |
| 2021 | 0.157 |
| 2022 | 0.163 |
| 2023 | 0.168 |

Abatement cost is used instead of the social cost of carbon because estimates of the social cost of carbon are highly uncertain. Moreover, the damage is severe and therefore should be restored when possible. Marginal abatement cost is preferred to the current market price of carbon because it represents the market price in a situation where every GHG emission would be priced to a level where climate goals would be reached[9]. Since this would increase demand for carbon credits, the price would go up. Annex A expands further on the reasons for the choice of using marginal abatement cost for valuation.

The study by Kuik et al. (2009) is chosen to estimate marginal abatement cost for the following reasons. It contains a meta-analysis of 62 marginal abatement cost observations analysed with a meta-regression, providing an economy-wide estimate instead of an industry specific value. Additionally, it is used and acknowledged by other actors within the field of cost-benefit analysis, such as CE Delft's environmental prices (de Bruyn et al., 2018). Moreover, the authors of the study are well-known, respected and frequently cited in their academic discipline (e.g., O. Kuik is cited more than 4,000 times and R.S.J. Tol more than 37,000 times). Finally, the value presented in the study presents a reasonable value compared to other values seen in the literature. Such other notable sources, that provide abatement cost values, are PBL (2019) and EcoCosts (Sustainability Impact Metrics, n.d.). Corresponding values are presented in Table 4 in Annex A. A potential downside of the selected study is that it was published in 2009, which may be considered outdated. However, at the moment of writing, a more recent meta-analysis of the abatement cost of carbon was not available.

# 8. Limitations and items for further research

## 8.1. Limitations

- The standard GHG footprint calculates global warming effects over 100 years. However, climate must stabilise already much earlier, and current global warming may have consequences for later climate dynamics. It is standard practice, but it may be that some greenhouse gasses have large effects in the short term, but not after 30 years. Timing of emissions may be relevant, for example because in the near future more opportunities to reduce greenhouse emissions and increase greenhouse gas sequestration might have been developed.
- The monetisation is based on abatement cost in a 2-degree scenario. This price is very uncertain, and not the same as the current abatement cost, or the net present value of expected damage cost, and the policy targets change over time. See Annex A for a further discussion of the issue.

[9] The 2-degree scenario as specified by the 2015 Paris Agreement is taken as reference climate goal.

Because the latter is too uncertain it is not used, while the 2-degree scenario is internationally agreed. Therefore, if policies are in place to reach this goal, the marginal abatement costs of such policies may be about the equilibrium cost estimated. So, the price is uncertain, but within a range that is commonly accepted.

- Emissions from land use and land use change are monetised the same way as other GHG emissions. A specific method to quantify them is not emphasized in this document, which recommends to use commonly accepted methods. Ultimately it is complicated and an object of discussion among experts how these should be calculated. According to some proponents, the mainstream methods largely underestimate these emissions (Searchinger, 2018).

## 8.2. Items for further development

- When available, implement more recent estimates than the abatement cost of carbon value determined by Kuik et al. (2009).
- The analysis of the consequences of land use and land use change for climate is complicated and not emphasized in the current method. Further research may start with the analysis of Searchinger et al. (2018) in comparison to other methodologies.
- The model for GWP of various GHG should be regularly reviewed over time, as the science on this aspect keeps developing. The current model, adopted by Recipe (Huijbregts et al., 2017), is following the guidelines of IPCC. IPCC updates these factors periodically, yet it is common practice to choose a fixed value in LCA. Further consideration on which factors are a better representation of GWP, should accompany the review of available up to date models.
- While from a rights-based approach it seems logical that some unavoidable greenhouse gas emissions are not unsustainable external costs, in practice all emissions will be priced. This is an operationalisation of the rights-based approach to true pricing which is required to build on an LCA approach and is consistent with the other environmental impacts of this method.

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# Annex A: Supplementary information on monetisation

For the monetisation approach of this module, we propose to use marginal abatement cost to monetise carbon emissions, and in particular the value of 0.152 $EUR_{2020}$/kg $CO_2$-eq , derived from Kuik et al. (2009). This annex provides three pieces of supplementary information. First, it compares the use of marginal abatement over the use of Social Cost of Carbon (SCC) and current market prices, the two main alternatives. Second, it discusses the technical aspect of updating abatement costs over time using the so-called Hotelling's rule. Third, it provides a comparison of the chosen value to other values often seen in the literature.

**Why not use current market prices?**

Actual carbon market prices (e.g., EU Emissions Trading System, ETS) were rising from 0.02 in May 2020 till 0.05 Euro per kg of $CO_2$ in May 2021. This represents a steep increase compared to the few years prior to 2019, where the price was below 0.01 Euro per kg for most of the time (see e.g., Markets Insider, n.d.).

Still, this is significantly lower than the value proposed in this method. The market for carbon is not fully functioning at the moment. When the ETS was set up, allowances were provided for free to economic actors. This has flooded the market with supply and kept the price low. Furthermore, only the companies with high emissions are included in the trading system.

Next to these markets, a (relatively smaller) voluntary market exists. On this market, compensation/restoration remediation measures are funded by consumers and organizations on a voluntary basis to offset their emissions (e.g., Trees for all, JustDiggit and (other) Gold Standard initiatives). Prices depend on the option chosen, but are typically low, with most options available below 0.01 Euro per kg of $CO_2$ and average prices around 0.003 Euro per kg (see e.g., Hamrick & Gallant, 2017).

Note however, that all the currently available options have limited capacity. This is well illustrated by the Global GHG abatement cost curve in Figure 2. The crucial point is that all bars that represent the abatement options have a limited width that represents their capacity or abatement potential. If there is higher demand for abatement, more expensive measures need to be taken. This is exactly what would happen if restoration and compensation were to be compulsory for all emitters. This is schematically sketched in Figure 3.

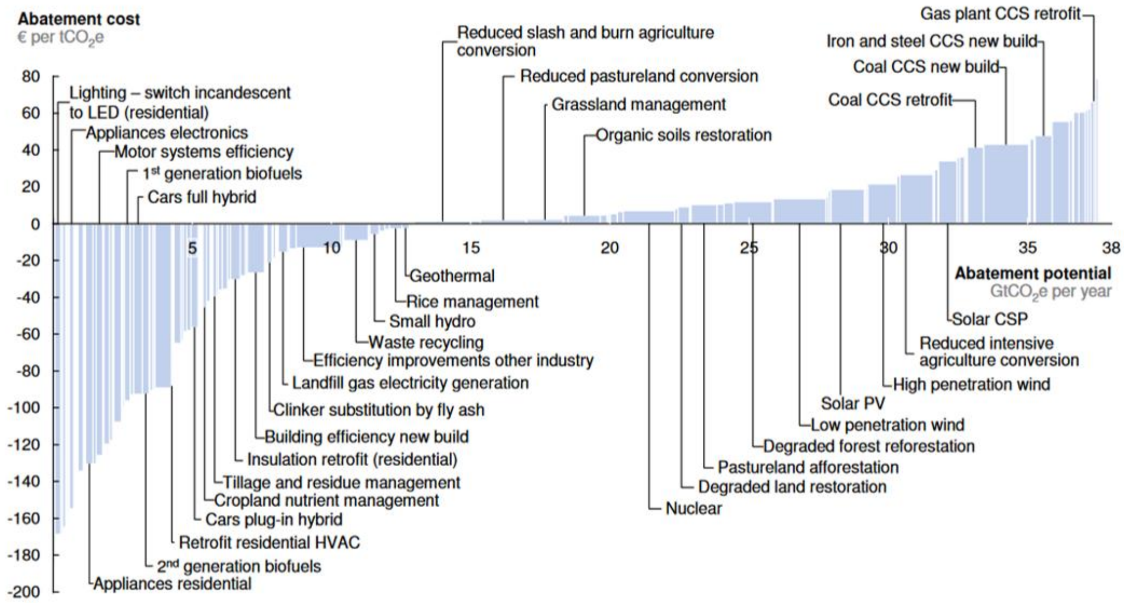


**Figure 2: Global GHG abatement cost curve beyond business-as-usual - 2030 (image from Enkvist et al., 2010)**

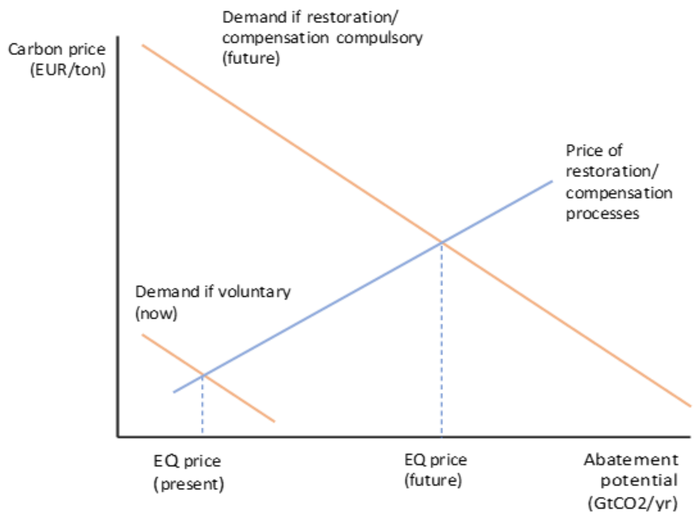


**Figure 3: (Hypothetical) supply and demand for carbon restoration/compensation now (demand for compensation is low, as this is not compulsory) and in a hypothetical situation where restoration/compensation would be compulsory, and the demand curve has shifted to the right**

We conclude that the current low prices available on carbon markets (both ETS and voluntary remediation markets) do not represent the situation in which the world aims to meet the Paris agreement targets, and there is a large global demand for abatement options.

**Why not use social cost of carbon?**

EPA (2017) describes Social Cost of Carbon (SCC) as '*a measure, in dollars, of the long-term damage done by a ton of carbon dioxide ($CO_2$) emissions in a given year*' (EPA, 2017). SCC is thus a form of damage cost. It describes the damage that would take place if no mitigation measures are taken to prevent that damage from occurring. If instead those mitigating measures *would* be taken, the damage need not materialise at all.

If abatement cost of carbon shows the cost of taking the required actions to limit climate change, the SCC shows the costs of inaction, to be weighed against other economic benefits. This, from a societal perspective, could be considered less relevant, from the moment that it is agreed that climate action is required (e.g., at the international level, in the Kyoto Protocol and the Paris agreements, SDG 13). This is in line with the true price valuation framework, which states that for each type of damage, one of restoration costs (of which marginal abatement is a form) and compensation (with the size of compensation determined by the damage cost) needs to be applied, depending on the type of damage caused. If the damage is severe and restoration is feasible, like in the case of climate change, restoration cost is preferred. This points to an abatement value rather than an SCC estimate.

In addition, assessment of the Social Cost of Carbon is complex. Calculating the SCC requires oversight of what all the forms of damage that relate to climate change could be. Typically, more recent assessments tend to include more effects and give higher values than older assessments (compare for instance the 2.1 cents per kg $CO_2$-eq of Tol (2008) with the 21 cents of Than (2015) or with the 38 cents of Ricke et al. (2018) in Table 4 below). A particularly difficult part of the assessment is the choice of a discount factor that determines how damage in the future is compared to damage in current times. Values around 3% are often used, but it is hard to justify this choice. In fact, EPA (2017) provides different values (ranging from 2.5% to 5%) and the resulting SCC can differ up to a factor 5[10].

Table 4 shows how the suggested value for abatement compares to SCC estimates. The considered abatement cost falls amongst the mid-range estimates, but some of the more recent SCC estimates are much above the suggested marginal abatement value.

**Theoretical behaviour of carbon prices over time**

The values in Kuik et al. (2009) are given for a number of years in the future. We suggest using the 2025 value, as this is closest to now. The values are expressed in fixed Euros as of 2025. The challenge is how to express this as a value for a given year, e.g. 2019[11], expressed in Euros as of that year. This requires the use of Hotelling's rule (see Hotelling, 1931 and Kuik et al., 2009).

Hotelling's rule, is originally formulated to describe the development over time, of the price of scarce non-renewable resources, that can only be extracted once (Hotelling, 1931). Carbon emission volumes can be argued to follow the same logic. In order to make the Paris agreement, given volumes can only be emitted once (see e.g., Kuik et al., 2009.)

Hotelling's rule states that the price of the resources in question grows not with the inflation, but with the applicable discount rate (Figure 4). Rational economic actors would speed up extraction if the price grows slower than the discount rate (until the price changes to match this). If the price grows slower than the discount rate, they would instead postpone extraction until the opposite result would be met. Kuik suggests using Hotelling's rule on the marginal abatement cost of carbon, with a discount rate of 3.5%[12] .

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[10] As an example, the 2015 value is 11 USD/ton $CO_2$-eq in the 'average impact' model with 2.5% discount rate, and 56 USD/ton $CO_2$-eq in the otherwise identical model with 5% discount rate.

[11] The year 2019 is chosen as the base year of comparison between the available cost factors, reviewed from a variety of relevant sources in this module. The same method is used to derive the factors for other years presented in Table 3.

[12] Values for Social cost of carbon, the main alternative for marginal abatement cost, also increase steeply over time. According to EPA, 2017 '*estimates of the social cost of these greenhouse gases increase over time because future emissions*


**Figure 4: Hotelling's rule, carbon price.**

### Values for monetising GHG emissions from different sources

Table 4 gives an (incomplete) overview of often-used values for the monetisation of GHG emissions ('carbon prices') from different sources. The table includes values for both abatement costs and for social cost of carbon (SCC). The suggested value, Kuik et al. (2009), is highlighted in blue.

**Table 4: Review of abatement cost factors, SCC factors and associated sources[13]**

| Source | Year | Original value in source | | Value in EUR 2019 | | Cost type |
|---|---|---|---|---|---|---|
| Tol (VU Amsterdam and U. of Sussex) | 2008 | 20 | USD2008/ ton | 0.021 | EUR2019/ kg | SCC |
| EPA (model 'average', 3% discount rate) | 2017 | 36 | USD2007/ ton in 2015 | 0.039 | EUR2019/ kg | SCC |
| De Bruyn (2017) (Lower bound) | 2015 | 60 | EUR2015/ ton | 0.062 | EUR2019/ kg | Abatement |
| Kuik et al. (Lower bound) | 2009 | 69 | EUR2005/ ton in 2025 | 0.076 | EUR2019/ kg | Abatement |
| De Bruyn (2017) (Central value) | 2015 | 80 | EUR2015/ ton | 0.083 | EUR2019/ kg | Abatement |
| EPA (model 'high impact', 3% discount rate) | 2015 | 105 | USD2007/ ton in 2015 | 0.115 | EUR2019/ kg | SCC |
| Kuik et al. (Central value) | 2009 | 129 | EUR2005/ ton in 2025 | 0.142 | EUR2019/ kg | Abatement |

*are expected to produce larger incremental damages as physical and economic systems become more stressed in response to greater climatic change, and because GDP is growing over time and many damage categories are modelled as proportional to gross GDP*'.

[13] Values to be reviewed, in particular the conversion to Euros as of 2019 – not all sources explicitly specify the way their value is expected to change over time.

| | | | | | | |
|---|---|---|---|---|---|---|
| Than (Stanford) | 2015 | 220 | USD2015/ ton | 0.205 | EUR2019/ kg | SCC |
| Kuik et al. (Upper bound) | 2009 | 241 | EUR2005/ ton in 2025 | 0.266 | EUR2019/ kg | Abatement |
| De Bruyn (2017) (Upper bound) | 2015 | 300 | EUR2015/ ton | 0.312 | EUR2019/ kg | Abatement |
| Ricke et al. (UCSD) | 2018 | 417 | USD2018/ ton | 0.376 | EUR2019/ kg | SCC |

# Annex B: The right to a safe, clean, healthy, and sustainable environment in international conventions

This annex provides an overview of how the right to a safe, clean, healthy, and sustainable environment is represented in various international conventions with relation to climate change. For a complete (preliminary) list of a list of rights, principles and obligations relevant to true pricing, please refer to the Principles of True Pricing (True Price Foundation, 2020).

*General*

- States should ensure a safe, clean, healthy and sustainable environment in order to respect, protect and fulfil human rights. *Framework principles on human rights and the environment, United Nations Human Rights special procedures, 2018 (principle 1)* (UN Human Rights Special Procedures, 2018)

- The impact of climate change, the unsustainable management and use of natural resources, the unsound management of chemicals and waste, the resulting loss of biodiversity and the decline in services provided by ecosystems may interfere with the enjoyment of a safe, clean, healthy and sustainable environment, and that environmental damage can have negative implications, both direct and indirect, for the effective enjoyment of all human rights. *Resolution adopted by the Human Rights Council on 22 March 2018 37/8. Human rights and the environment* (UN General Assembly, 2018)

- More than 100 States have recognized some form of a right to a healthy environment in, inter alia, international agreements, their constitutions, legislation or policies. *Resolution adopted by the Human Rights Council on 22 March 2018 37/8. Human rights and the environment* (UN General Assembly, 2018)

*Specifically with regards to the effects of climate change*

- "States have obligations to protect the enjoyment of human rights from environmental harm. These obligations encompass climate change." - *United Nations General Assembly, Report of the Special Rapporteur on the issue of human rights obligations relating to the enjoyment of a safe, clean, healthy and sustainable environment, 2016 (Human rights obligations relating to climate change)* (UN, 2016)

- "The Parties […] shall, individually or jointly, ensure that their aggregate anthropogenic carbon dioxide equivalent emissions of the greenhouse gases […] do not exceed their assigned amounts, calculated pursuant to their quantified emission limitation and reduction commitments […] and in accordance with the provisions of this Article, with a view to reducing their overall emissions of such gases by at least 5 per cent below 1990 levels in the commitment period 2008 to 2012." - *Kyoto protocol to the United Nations framework convention on climate change, United Nations, 1997 (article 3-1)* (UN, 1997)

- "This Agreement, in enhancing the implementation of the Convention, including its objective, aims to strengthen the global response to the threat of climate change, in the context of sustainable development and efforts to eradicate poverty, including by: (a) Holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change;," - *Paris Agreement, United Nations, 2015 (Article 2)* (UN, 2015b)

- "Take urgent action to combat climate change and its impacts" – *Sustainable development goal 13* (UN, 2015a)

# Glossary

| | |
|---|---|
| **Global Warming Potential (GWP)** | The Global Warming Potential (GWP) approach expresses the amount of additional radiative forcing integrated over a certain timeframe caused by an emission of 1 kg of GHG, equivalent to the additional radiative forcing integrated over that same period caused by the release of 1 kg of $CO_2$. |
| **Greenhouse Gases (GHG)** | Greenhouse gasses (GHG) include, carbon dioxide, methane and nitrous oxide, which are primary greenhouse gasses, and sulphur hexafluoride, hydrofluorocarbons and perfluorocarbons, which are identified as important by the Kyoto protocol. Emissions of GHG increase their atmospheric concentration (ppb), which in turn increases the radiative forcing capacity and consequently increases the global mean temperature. |
| **Stabilisation target for climate change** | Specified climate change or GHG emissions target, often in comparison to a corresponding baseline scenario (IPCC, 2007). |