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Cost-Benefit Analysis For Climate Action

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Summary

The European goal of achieving zero net emissions by 2050 is extremely ambitious. Action must be taken across a broad agenda driven by collective ambition. But it is also important to select projects and policy measures in the right economic order to alleviate the burden of the efforts for present generations. Although Cost-Benefit Analysis (CBA) has become the benchmark method to evaluate public policies since a long time, we argue that it should play a bigger role in the design and implementation of climate policies because abatement costs across and within sectors are highly heterogeneous.

When applied to decarbonation policies, CBA firstly requires the selection of a shadow price of carbon, to monetize the climate benefits of investments and policies. However, the whole assesment framework must be updated, including the time horizon, the discount rate and the pricing of climate risks. We show that such an updated framework leads to an upwards revision in the assessment of the climate benefits of green public investments and more broadly of mitigation actions.

Finally, there is a need to broaden the analysis beyond the efficiency criterion to deal with other dimensions of climate policies, such as their long-term effects on land use, or, above all, their distributive impacts. This requires specific analyses that should be articulated with CBA and carried out early to implement better climate policies than it has been done until now.

Résumé en français

L'objectif européen de zéro émissions nettes d'ici 2050 est extrêmement ambitieux, et l'atteindre va demander des efforts importants. Il est indispensable de sélectionner les projets et les mesures de politique économique rigoureusement pour en alléger le coût. Bien que l'analyse coûts-bénéfices (ACB) soit depuis longtemps la méthode de référence pour évaluer ex ante les politiques publiques, nous soutenons qu'elle devrait jouer un rôle plus important dans la conception et la mise en œuvre des politiques climatiques car les coûts d'abattement sectoriels sont très hétérogènes. Appliquée aux politiques de décarbonation, l'ABC exige tout d'abord la détermination d'un prix fictif du carbone, pour monétiser les bénéfices climatiques des investissements et des politiques. La totalité du cadre d'évaluation doit être adaptée pour prendre en compte les caractéristiques spécifiques de la question climatique : horizon temporel, taux d'actualisation, tarification des risques climatiques. Nous montrons qu'un tel cadre mis à jour conduit à réviser à la hausse l'évaluation des bénéfices climatiques des investissements publics verts et plus largement des actions d'atténuation. Il est également nécessaire d'élargir l'analyse au-delà du critère d'efficacité pour traiter d'autres dimensions des politiques climatiques, telles que leurs effets à long terme sur l'utilisation des terres et, surtout, leurs impacts distributifs. Cela nécessite des analyses spécifiques qui doivent être articulées avec l'ABC et menées très en amont pour mettre en œuvre des politiques climatiques meilleures que celles qui ont été mises en place jusqu’à présent.

JEL Codes : Q1
Mots clés : ACB, Politique climatique

Introduction

By the 2015 Paris Agreement, the Signatory States have given themselves the collective ambition of achieving net zero greenhouse gas (GHG) emissions – that is, a balance between GHG by sources and removals by carbon sinks. The Intergovernmental Panel on Climate Change (IPCC) has recently confirmed that this objective is necessary if we are to keep the temperature rise below 2°C.

The European Union wants to be at the forefront of this challenge. As mentioned in the communication of the European Commission for an "European Green Deal" (2019), the EU has already started to transform the economy to achieve climate neutrality, but "current policies will only reduce greenhouse gas emissions by 60% by 2050. Much remains to be done, starting with more ambitious climate action in the coming decade". In this perspective, all relevant climate-related policy will be reviewed, all sectoral policies being rethought. Carbon pricing must be aligned with climate objectives and the different pricing instruments must complement each other and jointly provide a coherent policy framework. Public investment and increased efforts to direct private capital towards climate action are needed to foster the deployment of innovative technologies and new infrastructures.

Achieving zero net emissions by 2050 is extremely ambitious and tricky. Action is called for simultaneously on multiple fronts, while the costs and emissions reduction potentials of many decarbonation technologies are still largely unknown, and in a general context where the acceptability of a tax on GHG emissions is poor, as demonstrated by the French case. Moreover, we do not have much time left. Efforts must be progressive enough to cushion negative demand shocks and limit the negative impacts of stranded assets, and determined enough to trigger behavioral changes and prevent the construction of new polluting assets such as coal-fired power plants.

Cost-Benefit Analysis (CBA) allows selecting the relevant actions and ensuring that the different levers are mutually reinforcing, by assessing the socio-economic value-added of projects or public policies and ranking them. Sound CBA is especially useful to weight the impacts at stake and to identify potential trade-offs or co-benefits between objectives. The practice of CBA has a long-standing tradition, dating back from the end of the 19th century. But it tends to play only a minor role in the policy making process of climate action. The aim of this paper is to underline the relevance of an updated and extended CBA framework to ensure that all the mitigation actions that we undertake are coherent and deployed in the right order. This claim will be illustrated through the (admittedly imperfect) example of the French practice of CBA.

In the context of climate action, the key parameter is the social value of mitigation activities (the so-called shadow price of carbon, or carbon value), which reflects the value put by society on measures aimed at avoiding the emission of one ton of CO_{2e}. The French government has recently asked a panel chaired by Alain Quinet (the "Quinet II Committee") to revise the carbon value used to evaluate French public policies, in order to align it with its new objective of carbon neutrality in 2050 (Quinet, 2019).

Building on this work, we will first emphasize why CBA is critical for the design of credible, ambitious and cost-effective climate policies (section 1). Then we will review the available evidence to select the appropriate carbon value (section 2). Finally, we will show that, beyond the choice of the carbon value trajectory, CBA applied to climate action raises specific challenges, stressing the need to adapt the whole assessment framework – reference scenario, time horizon and discount rates – and to complement aggregated CBA results by the analysis of compensations needed when climate policies have adverse distributive impacts (section 3).

1. The need to align a large variety of private and public actions

Carbon neutrality involves a large set of individual decisions, sectoral transformations, investments and policy decisions. Theoretically, their alignment could be achieved by the means of a unique carbon price, leaving to businesses and individuals the responsibility to adapt their behavior and to invest in low carbon solutions. However, the policy world is much more complex: deep decarbonation of human activities is necessarily based on a range of complementary measures, and experience shows that governments mobilize a large variety of policy instruments, with still a de facto limited role given to carbon pricing.

In this context, CBA has a major role to play because there is a huge heterogeneity of abatement costs across and within sectors, and therefore the need to define a merit order of policy actions to minimize the economic and social costs of decarbonation. Moreover, most measures have multidimensional impacts. Thus, CBA is needed to select the relevant mitigation actions, as well as the policy measures to foster those actions.

1.1. Heterogeneity of abatement costs and merit order of mitigation actions

Europe's ambition is to eliminate greenhouse gas emissions on European soil by 2050. This is the "Net-Zero" goal: *net* zero greenhouse gas emissions from human activity, with residual *gross* emissions to be absorbed by carbon sinks – which include forests, grasslands and, further down the road, carbon capture and storage technologies. This ambition must translate into public and private investments, and more generally actions undertaken by both the public and private sectors.

Action must be taken across a broad agenda driven by public policy, but also in the right order, by setting joint priorities, channeling resources towards meaningful initiatives and making the call between swiftly rolling out mature technologies or awaiting new solutions enabled by the innovations in progress. The whole economy is concerned: at the European level, energy use by the power sector, industry, transports and building is the main source of emissions but agriculture, industrial processes and waste management are also important emitters. The key to a successful energy transition lies in both changes in behavior and the establishment of a capital stock enabling GDP to be decoupled from emissions. This needs to redirect investment and funding towards low-carbon projects.

In this context, CBA can help to select appropriate projects and policies, with discounted net present values allowing comparison of temporally distributed impacts. Indeed, CBA is a set of valuation techniques to assess whether the benefits associated with a public intervention justify the opportunity cost of the resources used to achieve it. For that purpose, different methods have been developed to value non-monetary impacts.

Although CBA principles developed independently of environmental economics, the integration of environmental impacts in this framework has proved to be fruitful (Pearce, 2002) and it has been demonstrated that a common approach to costs was not detrimental to environmental ambitions. Thus, submitting environmental regulations to CBA has become a widespread practice to qualify the balance between the impacts of pollution on health or natural resources, and the economic costs of policies to reduce them. CBA has also integrated the need for human activity to take on board, "internalize", beyond the private benefits, the collective benefits to be reaped from reducing GHG. The corresponding cost is the social value of mitigation activities, the so-called "shadow price of carbon". It is the value that the community attaches to measures aimed at avoiding the emission of one ton of CO_{2e}.

The shadow price of carbon sets a baseline for calibrating climate policy: all actions that entail an abatement cost below the baseline must be undertaken as they are socially and economically viable. By this mean, CBA of mitigation actions weights emissions reductions with their abatement costs. The abatement cost is defined as the discounted cost gap between the decarbonation action and the equivalent carbonized reference solution, relating to GHG avoided by the action. The cost gap is discounted as the abatement cost incorporates costs connected with the initial investment as well as costs related to the investment's use throughout its lifespan.

The abatement costs should be assessed dynamically. The transition from coal to gas for example generates significant short-term GHG savings for a relatively low switching price (30€/tCO_{2e} at most), but involves installation of appliances that emit CO_{2e} in the long term. Conversely, some actions as photovoltaic solar panels installation and electric vehicle development entail a high initial cost but also have the potential to reduce the cost over time through economies of scale and learning effects.

On this basis, the abatement cost of a decarbonation action can be compared to the average discounted shadow carbon price throughout the equipment's lifespan. If it is lower than the shadow price, the sectoral action is useful from the community's point of view and should be implemented. If an action that reduces emissions by 1 tCO_{2e} a year for ten years represents a cost of €100 per metric ton of CO_{2e} avoided and the average discounted shadow price is €150 per metric ton, it may be regarded as relevant for the community. More generally any decarbonation action whose abatement cost is lower than the average of the shadow carbon price discounted over the action's duration is relevant for the community; other actions induce additional costs compared with more efficient pathways if no other dimensions are taken into account.

Why insist on the need for CBA in the area of climate action? Because the efficacy of mitigation actions is greatly heterogeneous (see for example Gillingham and Stock, 2018). It is not enough to compare partial efficacy ratios to build the climate policies. Synthetic balance results integrating all economic and environmental impacts must be considered.

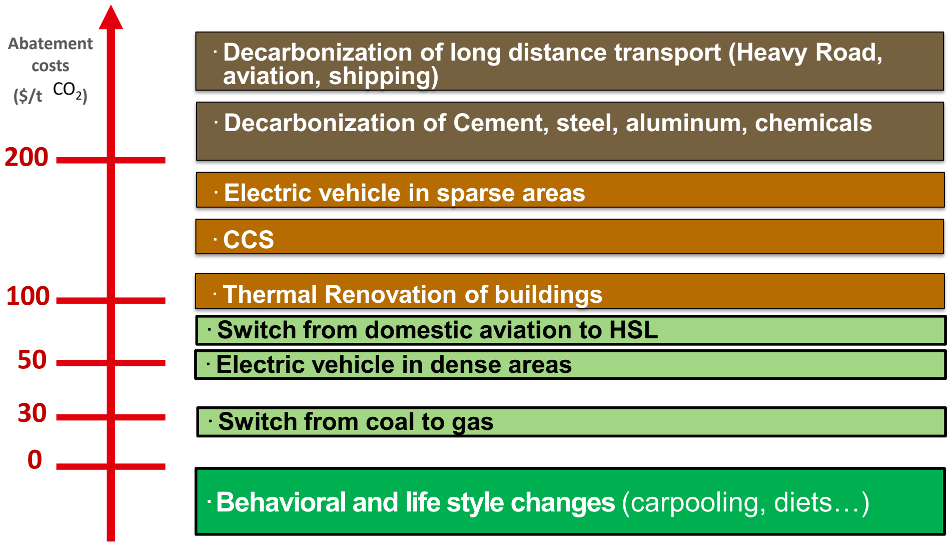
Figure 1 provides some rough estimates of abatement costs of selected GHG emission reduction strategies in Europe. It shows that decarbonation actions fall into three main categories:

- actions with zero or negative abatement costs, in particular because they do not involve significant investment or generate immediate savings. Such rare instances of a "free lunch" primarily entail restraint, e.g. purchasing a vehicle based on need rather than a larger, more powerful car when changing vehicle, adding a dose of ethanol into petrol, manual optimisation of a building's heating through the day or carpooling;

- actions with positive abatement costs that are lower than the baseline shadow price of carbon. These are actions that are not financially viable but appropriate for communities, which should be encouraged at the same time as improving their competitiveness;

- actions whose abatement costs remain high, based on current knowledge, such as the use of carbon-free hydrogen for transport, industry or energy production, or carbon capture and sequestration.

Figure 1: Estimates of abatement costs



Source: Authors' own compilations

1.2. An extensive toolkit of policy instruments, with a limited role of carbon prices yet

The decarbonation of our economies requires new energy and transportation infrastructures and fundamental research, for example to create efficient ambient carbon capture technologies. However, most abatement sources are diffuse and dispersed among all businesses and households. Public policies - carbon pricing, subsidies to green behavior or carbon emissions standards - are needed to stimulate private agents' abatement efforts.

In this context, most economists underline "that a price on polluting activities is a crucial and efficient way to reduce GHG emissions, even though not the only instrument" (EAERE, 2019). The excess of emissions coming from the fact that economic agents do not internalize the negative externalities that they impose when they emit CO_{2e}, the most direct solution is to implement the so-called polluter-pays principle. With carbon pricing, climate goals can be achieved under economically efficient conditions since agents are encouraged to carry out all decarbonation actions of lower cost than the carbon price, too high-cost actions being set aside, without the State needing to know specific agents' abatement costs or monitor their actions in detail. In addition, companies are encouraged to innovate in order to propose decarbonized solutions, whereas command and control regulations do not reward investment that exceeds the standard.

Establishing a transparent carbon pricing plan for the years ahead is thus a priority. Indeed, most infrastructure and R&D investments to reduce GHG emissions have in common that they are irreversible (sunk) costs and yield a delayed reduction of emissions over an extended time span. What triggers an investment in these sectors is not the current price of CO_{2e} but the expectations of high prices in the future. Uncertainty about carbon pricing of renewable investment policies could also impede investment. Therefore, the carbon price path should be set on a multi-year basis.

However, there remains a lot of controversies about the choice of instruments to establish effective carbon prices, the possibility to apply a uniform price, the ability of non-price instruments to replace carbon pricing when it proves difficult to implement, the risks of instruments' overlap, the effective complementarity of other instruments with carbon prices and their articulation, etc. The different views in these areas have consequences on the role of CBA.

Within the strictest "Pigovian" approach, environmental policies should basically price external costs. Then, the role of CBA is straightforward: 1/ Select a shadow price of carbon; 2/ Introduce an effective price of carbon in line with this shadow price and let the private sector adapt to the shift in relative prices; 3/ Use this shadow price to evaluate public green investments.

The policy-making process is more complicated indeed if all public policies cannot be simultaneously aligned on the net zero GHG emissions goal, which would require among other things that:

- urban planning and mobility policies are consistent with each other, in order to reduce travel needs;

- decarbonized alternatives (low carbon infrastructure networks and technological solutions), and resources for funding viable decarbonation investments (access to credit, facility, and public guarantees covering the various risks involved) are available;

- the State is able to separate the question of implementing effective carbon pricing from that of dealing with its distributive effects and impacts on competition, for example by adopting compensatory provisions.

In addition, carbon pricing is subject to constraints as it may affect households' purchasing power and firms' competitiveness under conditions that existing redistribution mechanisms cannot address properly. If a comprehensive and equitable strategy to make carbon pricing more acceptable is not politically feasible, a "second-best" strategy would consist in less ambitious carbon taxes or emission trading systems complemented, or even replaced by a more forceful use of feebates or regulations.

According to the Stern-Stiglitz Commission (2017), carbon pricing by itself may not be sufficient to induce change at the pace and on the scale required for the Paris target to be met, and may need to be complemented by other well-designed policies tackling various market and government failures, as well as other imperfection. "Based on industry and policy experience, and the literature reviewed, duly considering the respective strengths and limitations of these information sources, this Commission concludes that the explicit carbon-price level consistent with achieving the Paris temperature target is at least US\$40–80/tCO_{2e} by 2020 and US\$50–100/tCO_{2e} by 2030, provided a supportive policy environment is in place". This Commission emphasizes that transition to net zero GHG emissions should be based on the alignment of all public policies towards the "Net-Zero" goal by "smart" aggregation of complementary measures.

More generally, a variety of models suggest that an optimal portfolio of policies can reduce emissions at a significantly lower social cost than any single policy in the presence of multiple market or political economy failures: asymmetric information and principal-agent problems in energy efficiency; knowledge spillovers; and, more generally, the public good nature of technological innovation for climate mitigation.

In practice, the toolkit of environmental instruments is extensive. However, to be effective, additional instruments must actually alleviate the constraints and enlarge the set of feasibility of public policies. This is far from automatic as is the coherence of mixes of policies. Most of the time, the use of multiple instruments reflects an incremental ad-hoc approach to climate policy, and instruments are introduced in a piecemeal, overlapping way.

For instance, at the European level, different legislations aim at achieving the EU three objectives: reducing GHG emissions, deploying renewable sources of energy, increasing energy efficiency. The main policy instrument, the European Emissions Trading Scheme (EU ETS), covers 45% of European emissions from more than 11,000 heavy energy-using installations (power stations and industrial plants) and airlines operating between European countries. On top of the EU ETS, many member States have introduced carbon taxes (notably Sweden, Norway, Denmark, France, the UK, Ireland) and provided generous subsidies or feed-in tariffs for renewable electricity (most notably Germany, Spain and France). In all countries a large number of regulations have been introduced, for example standards for the emission rates of vehicles and power generators, for the energy efficiency of electricity-using products, or minimum requirements for the use of renewables in power generation. Besides, instruments such as fuel taxes were not introduced with GHG emissions reductions as their primary goal, but they nonetheless increase the consumer fuel price and constitute the policy environment on top of which more ambitious climate policies were introduced.

The current package has delivered some significant results: in 2017, GHG emissions in the EU-28 were reduced by 22 % compared with 1990 levels, representing an absolute reduction of 1 240 million tons of CO_{2e}, putting the EU on track to surpass its 2020 target, which is to reduce GHG emissions by 20% by 2020 and by 40% by 2030 compared to 1990. Despite this significant achievement, the cost-effectiveness of this policy package cannot be considered as optimal. At present the policy instruments in the European Union are unbalanced and overlap in different ways.

First, the vast majority of policy instruments introduced by European countries to curb their GHG emissions are not primarily based on carbon pricing. The OECD (2018) measures the Carbon Pricing Gap, i.e. the carbon price deficit of OECD countries and the G20 by comparison with a baseline of €30/tCO_{2e}: in 2018, the deficit was 76.5%. Although carbon pricing is more developed in the European Union than in other parts of the world, the carbon pricing gap remains significant for all major European economies (Table 1).

Table 1: Effective carbon pricing gap of main European countries (%)
(for a carbon benchmark rate of 30€/tCO_{2e})

France	41
Germany	53
Italy	46
Poland	67
Spain	51
Sweden	63

Source : OECD (2018)

Second, many countries currently subsidize renewables and fossil fuels at the same time when tax incentives for electric vehicles may have no effect on average vehicle emission rates in the presence of binding fuel economy standards. The depressed carbon price signal on the EU ETS is partly due to counteractive interactions with renewable energy and energy efficiency policies, which contributed to create an imbalance between supply and demand. In the case of an emissions-trading system in which the emissions limit is set, efficiency measures and support to low-carbon technologies should lower the market price of emissions allowances, as the cost of reduction is supported by other programs. By lowering the market price of allowances such measures also lower its downstream effects, e.g. the increase in wholesale electricity prices via the pass-through of the allowances by power utilities.

1.3. Multidimensional impacts

The relevance of CBA in the context of climate policies must also be emphasized because mitigation actions generally have multidimensional impacts. Then, there is a danger of overlooking policies whose efficacy comes from the combination of 'co-benefits'. The emblematic example is provided by the phasing-out of coal, which generates both climate and health benefits. Another example would be a new railway line generating both time savings and emission reductions.

There is also a (symmetrical) danger of paying insufficient attention to trade-offs that need to be considered. For example, the promotion of biking provides climate and cardiovascular benefits, but the risk of accidents must also be borne in mind for the design of appropriate roads. The general nature of the problem can be illustrated by numerous examples of past policies failures: neglect of particles emissions of wood energy; mistakes made in the management of vehicle fleets through a bonus system considering only CO_{2e} emissions, and not NO_x and fine particles; need to compare nuclear risks with the social cost of the emissions from fossil-fired power plants which are necessary for supplementing renewables intermittency, etc.

Thus, it is not enough to compare partial efficacy ratios of emissions to build these policies. CBAs are essential both to evaluate synergic impacts on solid grounds and to clarify trade-offs to be managed. They are also essential to integrate the effective impacts of policies, especially rebound effects. By this term, we refer to the observation that in general more effective equipment such like low-emitting cars are used more intensively. Therefore, the impact of higher emissions standards on CO_2 emissions needs to be estimated with the induced mileage change, in the absence of incentives to reduce car use. Moreover, as long as equipment is polluting, green subsidies partly remain climate-damageable subsidies since they encourage the use of polluting products.

What is true for vehicles also applies to housing: stricter thermal regulations or refurbishment of poorly insulated buildings often lead to increased temperatures in the dwellings. This comfort effect has a value for the inhabitants, especially for the poorest, which can be estimated in terms of consumer surplus. CBA must simultaneously consider effective CO_{2e} emissions, taking into account rebound effects: the merit of CBA is that it allows all these impacts to be synthetized, with justified relative weights. Often, this process suggests studying complementary measures to limit side-effects and the relative performance of the different packages of instruments can thus be compared by these means.

All in all, faced with these problems of heterogeneity of abatement costs, of multiple instruments and of multidimensional impacts, CBA appears necessary to underpin the policy-making process and minimize the transition costs. When the government opts to use non-pricing instruments – usually regulations or subsidies – detailed knowledge of abatement costs becomes essential to efficiency: too low a level of subsidy or light-touch regulation is inefficient; too high a level of subsidy creates rent-seeking; overly stringent regulation may impose compliance costs in excess of the baseline price of carbon. Appropriate calibration of climate policy therefore depends on the capacity of the government to know and track in detail the actual abatement costs.

2. What carbon value to carry out CBA of climate policies?

Carbon valuation can involve two approaches: the cost-benefit approach, defining the social cost of carbon as the sum of discounted marginal damages due to climate change, and the cost-effectiveness approach, computing the shadow price of a given carbon budget. The increasing divergence between the two raise important questions: does it suggest that cost-benefit models minimize the cost of damage, or, conversely, that climate policy targets underestimate the cost of emissions reduction?

However, the relevance of each approach also depends on the level of decisions under scrutiny. The definition of a global ambition needs to consider damages. At the level of national policies, the question becomes less "why and how much" than how to achieve a committed goal at lowest cost.

2.1. Estimating the social cost of carbon: mission impossible?

The cost-benefit approach involves achieving an overall discounted valuation of all short, medium and long-term damages caused by the emission of one ton of CO_{2e}. The comparison between the marginal cost of damage and the marginal abatement cost will determine the socially optimal path to reducing emissions. The price of carbon, known in this approach as the Social Cost of Carbon (SCC), assigns a monetary value to the social cost of damage and, correspondingly, the welfare gains from a reduction in emissions. Adopting this approach acts in principle as a hedge against two risks: making too much effort for too little social benefit; and not making enough effort to attain a high benefit despite a low associated cost.

It is instructive to set out the three main elements in calculating the marginal cost of damage.

- Monetary value of damage. Modelling climate externalities essentially depends on two parameters: climate sensitivity, i.e. the increase in temperature caused by doubling the GHG atmospheric concentration; and the climate damage function, which captures the impact of rising temperatures on welfare. The cost of damage or cost of inaction is expressed in monetary terms but consists of both market costs (e.g. loss of productivity and GDP, lower agricultural yields, destruction of productive capital due to natural disasters, etc.) and non-market costs (e.g. loss of biodiversity, destruction of ecosystems, etc.), to which we assign a monetary value. Assigning a value to damage is therefore subject to considerable uncertainty: how do we aggregate such a wide range of impacts and give a monetary value to what are in part non-market damages? Is the damage function multiplicative (i.e. is damage correlated to the level of GDP) or additive (i.e. is damage independent of the level of GDP)? What is the degree of convexity of the damage function?

- Discounting for damage caused over time. The marginal cost of damage caused in the future by the emission of one ton of CO_{2e} today must be discounted in order to be tracked to its present value. Over the very long term – a horizon much longer than that used in financial markets – the discount rate involves ethical choices: pure time preference, aversion to intra- and intergenerational inequality, assessing the long-term outlook and its attendant uncertainties (Stern, 2006; Gollier, 2012). This is especially important in the context of global warming, given that large-scale changes are at risk of occurring by the end of the century.

- Accounting for the risk of serious and irreversible damage, over and above marginal damage (Weitzman, 2014).

CBAs have ultimately been few in number. Only a handful of integrated assessment models have been used in major international studies, notably DICE (see, for the most recent version of the model, Nordhaus, 2018), FUND (Anthoff & Tol, 2014) and PAGE (Hope, 2006). These models are intended to overcome the major methodological issues that heavily influence the conclusions that they reach. In fact, ranges for the social cost of carbon are relatively broad – between $30 and $150 per ton of CO_{2e}. Table 2 sets out a non-exhaustive list of figures for the social cost of carbon from two recent major studies: Nordhaus (2018), using DICE, and an analysis by the United States Interagency Working Group, comparing DICE, FUND and PAGE (USIWG, 2016).

Table 2: The Social Cost of Carbon (per ton of CO_2)

	2015	2020	2050
DICE (values in $ 2010)			
Discount rate of 4.25%	30	35	98
Discount rate of 2.5%	111	133	242
US IWG (values in $ 2007)			
Discount rate of 3%	36	42	69
Discount rate of 2.5%	105	123	212

Sources: Nordhaus (2018), US Interagency Working Group (2016).

Recent economic research suggests that cost-benefit approaches tend to underestimate the cost of damage and therefore apply much larger carbon budgets than those implicit in new climate change targets. There are three interrelated reasons for this underestimation:

- models generally do not take into account all potential damages, some of which are difficult to assign a monetary value to because they have no direct impact on GDP and asset values, or do not factor in the most recent, more pessimistic valuations (Aufhammer, 2018);
- climate change has traditionally been assumed to affect GDP through productivity, dwindling capital stock and destruction from natural disasters. However, an emerging body of research suggests that the growth rate can also be affected by a reduction in the capital stock or productivity gains, in particular in poor countries and countries vulnerable to climate change (Moore and Diaz, 2015; Dietz and Stern, 2015);
- models underestimate the risk of disaster in the case of marked increases in temperature (Stern, 2016).

In this respect, a fundamental criticism applies to the degree of relevance of cost-benefit analysis, which compares the marginal cost of action and inaction, typically using normal probability distributions. However, climate change includes non-marginal risks of catastrophic damage, with probabilities of occurrence which, despite being unclear, are considerably higher than those obtained from a normal distribution (Weitzmann, 2014; Van der Ploeg and de Zeuw, 2014). In his Dismal Theorem, Weitzman (2011, 2014) describes a scenario in which the social cost of carbon tends to infinity, where the probability of catastrophe falls at a slower pace than the scale of catastrophic damage increases. Weitzman considered the implications of this outcome "absurd": current generations cannot devote all of their resources to disaster risk prevention, and the conditions under which the Dismal Theorem holds are undoubtedly highly restrictive. However, the message of caution when implementing and interpreting cost-benefit assessments remains valid: the value of emission reductions should not only be measured by avoided damages but also by the reduced probability of the occurrence of irreversible catastrophes.

In this context, the IPCC scientific community has been guarded about the use of cost-benefit approaches to determine the optimal level of damage, preferring instead to keep to the definition of maximum temperature thresholds for preventing the risk of serious and irreversible damage. Overall, the main argument for more ambitious mitigation policies than those based on the cost-benefit models' output lies in the finding that both GHG concentrations and damages are irreversible.

The irreversibility of GHG concentrations is linked to current levels of technological advancement. Negative emissions technology may reverse GHG inventories, but the prospect of such a development remains wholly speculative at this point, and the prudent approach would be to expect a dwindling and/or depleted carbon budget.

Even if one assumes that emissions become partially reversible in the future, some of the damage caused will be irreversible, meaning that the assistance currently offered by nature that will have disappeared will not be able to be replaced by technological assistance. Front-loading and increasing efforts provide an option value against the risk of there being no room for manoeuvre in the future.

2.2. Cost-effectiveness approaches

Highlighting the limitations of existing cost-benefit approaches does not mean that the economic and social costs of mitigation to meet these thresholds can be ignored. A cost-effectiveness approach makes it possible, through a carbon price path, to measure the economic effect of mitigation actions, the required decarbonation investment and the risk of stranded costs to meet a given climate target.

With the cost-effectiveness approach, an abatement target is exogenously set, and the level and trajectory of carbon prices are computed in order to reach that target in the most efficient way. In this case, the carbon price is the dual variable of the quantitative constraint – for this reason, it is known as the Shadow Price of Carbon (SPC). This approach may appear secondary to the cost-benefit approach, but it abstracts from discussions over the cost and discount rate of damages and has a sound methodological basis – as applied to optimal management of non-renewable resources.

As the climate externality is related to the level of GHG concentration in the atmosphere, targets are expressed in terms of the carbon budget, i.e. the maximum net accumulation of CO_2 over a given period, at or below which rises in temperatures are restrained. With this approach, the carbon price level depends on the size of the carbon budget, available carbon sinks, decarbonation technology, achievable behavioural changes towards reaching the targets, as well as the availability of flexible international mechanisms (e.g. purchasing emissions permits on international markets, availability of carbon sinks in other countries, etc.).

The slope of the carbon price path is consistent with the optimization of the extraction of a scarce natural resource. The price of the scarce resource will increase over time due to its increasing scarcity. Specifically, the price of a ton of CO_{2e} is intended to increase at the discount rate: Hotelling's rule holds that the discount rate should equal unit changes in the carbon price, thereby protecting future values. Correspondingly, it protects against the risk of creating an incentive to postpone investment, as would be the case if the price grew faster than the discount rate – which is known as the Green Paradox (Sinn, 2015).

The well-defined cost-effectiveness analytical framework must confront another challenge, namely the rapid depletion of carbon budgets. The fifth report of the IPCC, published in 2013 and 2014, demonstrated that in the absence of specific efforts to reduce emissions, the global carbon budget to limit temperature increases to 2°C would run out by the middle of the century (IPCC, 2014). The IPCC also noted that a conservative estimate of the potential volume of negative emissions would make the second half of the 21st century a viable target for achieving carbon neutrality, i.e. a balance between gross GHG emissions and carbon sinks. These findings underpinned the 2015 Paris Agreement.

2.3 A recent sharp upwards revision in shadow prices

Carbon prices linked to decarbonation targets are subject to significant upward revision in response to a dwindling carbon budget and more stringent targets. Table 3 gives the mean world carbon prices based on simulations carried out by the IPCC, recognising that the dispersion is high around these mean values. Predictably, prices rise as the urgency of decarbonation increases. In addition, in the “1.5°C" scenarios, prices pass the $100 mark by 2030, before “taking off” after 2030.

The table highlights the difficulties associated with modelling the transition towards a carbon-neutral economy. Models give plausible values for required future carbon prices through to 2030 and 2040, or alternatively until emissions have fallen broadly in line with “Factor 4” scenarios (i.e. reductions in greenhouse gas emission levels by a factor of four from 1990 levels).

The robustness of model output declines when the horizon is farther. As the level of emissions falls down, reductions become harder to achieve and require structural, non-marginal changes, which models calibrated on the cost of existing or foreseeable technologies can no longer predict. Lastly, it is noted that the slope of price paths between 2030 and 2050 is markedly higher than under Hotelling's Rule, which suggests that the need for initial effort is still underestimated by current policies.

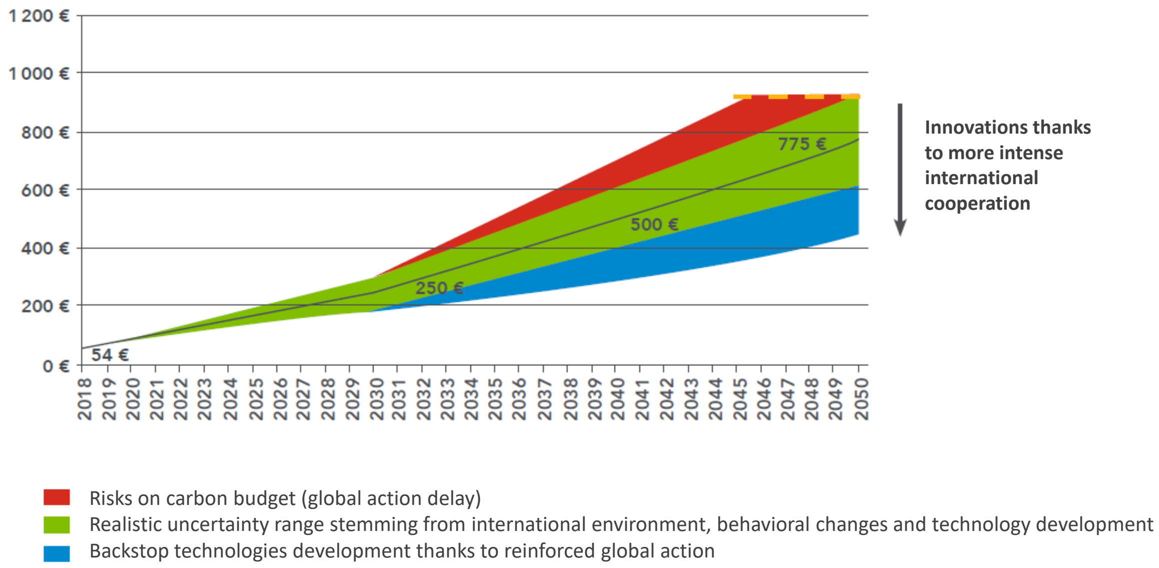
Table 3: Carbon price under IPCC calculations (in $2010 per ton of CO_2)

Scenario	Content	Carbon prices in 2030	Carbon prices in 2050
1.5°C	Probability of exceeding 1.5°C less than 34%	$1,472/t	$ 3,978/t
1.5°C low	Probability of exceeding 1.5°C between 34% and 50%	$ 334/t	$ 1,026/t
1.5°C high	Probability of exceeding 1.5°C between 50 and 67%	$ 129/t	$ 586/t
Lower 2°C	Probability of exceeding 2°C less than 34%	$ 164/t	$ 518/t
Higher 2°C	Probability of exceeding 2°C between 34% and 50%	$ 56/t	$ 169/t
Above 2°C	Probability of exceeding 2°C more than 34%	$ 21/t	$ 63/t

Notes: in each scenario, average price for a range of models and simulations.
Source: IPCC (2018).

In France the shadow price recently proposed at the 2030 horizon by the second Quinet Commission is significantly higher than that taken from the 2008 previous report (€100 at 2008 values, €110 at current values). This revision primarily reflects that action has been delayed until now and the resulting necessary increased ambition beyond Factor 4. This goal entails high abatement costs or technological breakthroughs in a number of economic sectors, particularly agriculture (notably the need to adapt crop and livestock farming), in some industrial sectors (the need to find substitutes or disruptive technologies in essential production such as cement, chemicals and steel), and in long-distance transport (land, sea and air travel). The increase in shadow carbon prices also reflects the lack of international cooperation and flexible mechanisms at international level. The shadow price of carbon in France is within the range of values indicated in the IPCC's latest October 2018 report for targets under two degrees, and was revised sharply upwards to factor in the risk of rapid depletion of world carbon budgets.

Figure 2: The French Shadow Price of Carbon



Source: Quinet (2019)

Determining a carbon price path at a country level must account for uncertainty around valuation which increases further into the future as the scope for technological developments and diplomatic initiatives expands.

The sensitivity of results to the cost of technology is closely related to underlying assumptions of international cooperation. For industry, research and innovation efforts that place greater focus on decarbonation and are simultaneously engaged in multiple countries would have a powerful impact in terms of reducing the cost of technology, as can be seen at present in the case of renewable energy. Where multiple research bodies and companies in a number of countries become engaged in innovation projects, this should produce gains for individual countries: each country benefits from the emergence and dissemination of innovation throughout the world, along with the reduction in the cost of technology facilitated by learning effects and economies of scale. These are considered the international spillover effects.

Overall, the assumption of technological breakthroughs through closer international cooperation would undoubtedly have little effect on the price of carbon in 2030, but would accommodate an expected sharp reduction in the carbon price beyond 2030 (from €775 to €450; see green area in Figure 2). On the other hand, a deficit in international cooperation would not justify an upward revision in the already-high baseline carbon price in France (see red area in Figure 2); any such revision would prevent deployment of additional technologies within the same short timescale and could lead to restrictions in business activity and employment, with no sustainable benefit from the fall in the carbon intensity of human activity.

3. Implementation of CBA with carbon prices

Evaluating the costs and benefits of mitigation actions or, more generally, the climate impact of policy actions, raises three main challenges.

First, it is necessary to evaluate the relevant price of carbon used to monetize the climate impacts of investments and policies, as seen above.

Second, there is a need to extend the traditional CBA framework by providing answers to a number of crucial questions, such as: What is the relevant reference scenario, against which projects should be evaluated? How should the climate risk be taken into account in the choice of the discount rate? This has notably resulted in an increasing role of climate change in the economic appraisal. Within the new framework, climate change has a non-negligible impact for CBA.

Finally, there is a need to broaden the analysis beyond the efficiency criterion to deal with other dimensions of climate policies, such as their long term effects on land use, or, above all, their distributive impacts. This requires specific analyses which should be articulated with CBA and carried out early, in order to implement better climate policies than it has been done until now.

3.1 The evolution of the practice of CBA in France

In France, the practice of CBA has a long-standing tradition. Jules Dupuit, the nineteenth-century French engineer, is considered as the precursor of modern cost-benefit analysis. CBA is also a well-established practice for infrastructure choices and it is mandatory for major public investments.

A first set of values for the shadow price of carbon was defined by a French official guideline for public CBA in the field of transportation projects at the beginning of the 2000s (Boiteux, 2001). Its value was initially set at the level of 27€/tCO_{2e}. Then, this value has been reconsidered by a specific committee commissioned by the government on this topic, chaired by Alain Quinet (Quinet, 2008). Given the French objectives in terms of CO_2 reduction at this date, the commission recommended a shadow price of carbon of €100 $_{2008}$/tCO_{2e} in 2030. A new committee, also chaired by Alain Quinet, has reviewed this value after the 2015 Paris Agreement (Quinet, 2019), and considered that the shadow price of carbon should increase significantly, up to €250/tCO_{2e} in 2030.

Both "Quinet reports" make clear that the carbon shadow price should be used in the evaluation of all public policies. The "Quinet II" report emphasizes that the primary purpose of the social value of mitigation activities is to provide a reference for an updated assessment framework addressing four key questions:

- is the country on the "right" track towards decarbonation – that is on course to ultimately meet the "Net-Zero" goal? The answer to this question can be found in a quantitative monitoring of emission flows per sector and of carbon sinks;
- does the observed trajectory enable the goal to be achieved at the least cost? This is where the shadow price of carbon comes in as a useful guide, insofar as it enables a definition of the scope of relevant actions for the community. A higher shadow price of carbon extends the scope of socially profitable actions: all initiatives – whether public or private – presenting an abatement cost lower than the shadow price of carbon should be undertaken whenever possible. When this cannot be done, the barriers and obstacles to such actions must be identified;

- are the initiatives ranked by merit order? All sorts of measures can be applied to achieve the target, but they must be undertaken in the right order. Low-cost drivers for reducing CO_{2e} emissions must be leveraged as a priority, before costlier measures are taken. This is where the merits of a multi-year trajectory for a shadow price of carbon that rises over time become clear, as it can guide the activation at the right time (so not too early and not too late) of effective action, with account taken of the required investment timeframes;

- do private stakeholders initiate measures of their own accord, or is public intervention required? In some cases, measures are cost-free and sometimes even generate gains. This is often the case with behavioral changes towards "sober" lifestyles, equipment-sharing strategies and certain efforts to achieve greater energy efficiency. In other cases, the externality is not factored in and requires public intervention in the form of investment or incentives and regulatory measures.

Using a relevant shadow price of carbon is not the end of the story to address these questions. During the last decades, the greater concern of the society for climate change has influenced the practice of CBA. The time horizon and the associated discount rate have also been crucial issues.

3.2 An extended assessment framework

CBA was traditionally performed for a limited time period. An infrastructure investment was generally assessed for a period of 30 to 50 years. Thus, the social benefits after this period were not considered. Now, the time horizon has been extended and the social discount rate revised downwards. This has been an important argument for enhanced climate policies.

Table 4 highlights the shift over the last 20 years in the main parameters of the assessment framework and provides an example of the impact of these changes on the socioeconomic value of a railways high speed line (HSL), more precisely the second phase of the high speed line between Paris and Strasbourg, representing 106 km of railways and costs of €2.1 billion. The climate benefits of the modal shift from air or car transport to rail have been significantly revised upwards: from 2.8% of the initial investment cost to 12.9% according to the new framework.

Table 4: Evolution of socioeconomic methods

	Boiteux (2001)	Quinet 1 (2008)	Quinet 2 (2019)
Social discount rate	8%	4%	4.5%
Shadow price of carbon (€/tCO_2t)			
in 2010	32	32	32
in 2030	58	100	250
in 2050	104	180	775
Period of assessment	50 years	50 years	until 2140
Long run growth of the shadow price of carbon (% p a.)	3%	4%	4.5% until 2060, constant afterwards
Climate mitigation benefits of the HSL Paris-Strasbourg Phase II (% of investments costs)	*2.8*	*5.1*	*12.4*

Source : Authors' own compilations and estimates

To illustrate further the increased impact of climate concerns we carry out some simulations based on a simplified set of assumptions. We first consider a country with an initial shadow price of carbon growing over time at 4.5% up to 2050 at 2 different time horizons. In this exercise the effective carbon price is considered equivalent to 0. For an investment of 2.1b€ leading to a modal shift of 450 000 passengers (such as the HSL Paris-Strasbourg Phase II) the climate benefits are not sufficient enough to justify the project but nevertheless represent a significant long term benefit (see Table 5).

Table 5 : Climate benefits of a HSL (as a share of initial investment)

	Time horizon (years)	
Initial shadow price of carbon	50	100
50€	3.1	3.7
100€	6.8	8.3

Source : Authors' own compilations and estimates

We then consider a situation where the effective carbon price is equal to the shadow price of carbon under the same underlying assumptions. The modal shift is more important, adding a climate benefit gain of 1.3 to 3.5 points (see Table 6).

Table 6 : Climate benefits of a HSL (as a share of initial investment)

	Time horizon (years)	
Initial shadow price of carbon	50	100
50€	4.4	5.5
100€	9.4	11.8

Source : Authors' own compilations and estimates

The discount rate used in CBA represents the rate of return required to consider that a project and, more generally, public policies with long-term consequences, are socially desirable to implement. Its level depends on a variety of parameters that determine what we should do for the future: collective preferences for the present and risk-aversion, expected per capita GDP growth, weight placed on impacts in the distant and uncertain future. However, the benefits of avoided damages remain uncertain, as are also abatement costs and decarbonization technologies.

The underlying question is that of "risk-premia" to be integrated in CBA. It had been addressed by a Committee chaired by Christian Gollier, whose general outline was that projects which provide insurance against macroconomic shocks should be favored and, on the contrary, that the social net present value of projects whose benefits are highly (positively) correlated with growth is overestimated if CBA only discounts mean expectations of impacts (Gollier, 2011). This issue is of particular importance in the context of climate policies since most of associated risks are not diversifiable.

In this perspective, Gollier (2019) argues that the discount rate used to value these policies should include, in addition to the risk-free rate, a "climate beta", reflecting the negative correlation between the marginal abatement cost and aggregate consumption: if the carbon budget is revised downwards, this increases the marginal abatement cost (assumed to be increasing) and restricts consumption possibilities; if, on the other hand, the carbon budget is higher than initially expected, the marginal abatement cost will be lower and consumption higher.

Thus, uncertainty over the carbon budget supports a high initial price and a growth rate of the price below the discount rate, in order to seamlessly absorb mid-point revisions to the carbon budget. This reasoning also applies when uncertainty affects decarbonization technology: in the event of unforeseen advances, the future marginal abatement cost will be lower and consumption higher.

On the other hand, when macroeconomic conditions are the main cause of uncertainty, the correlation between the marginal abatement cost and consumption is positive. When growth is higher than forecast, emissions will be higher, as will the marginal abatement cost as a consequence, resulting in a positive "beta" value. In this configuration, the benefit from an investment to reduce emissions increases over time, and is higher than the discount rate – returns from this investment thus take the form of a risk premium. The initial price of carbon is therefore lower and its growth rate higher than the discount rate.

3.3 A new issue: which baseline scenario to be considered when countries aim at achieving carbon neutrality?

The choice of the baseline, that is the reference scenario, is a crucial issue. Socioeconomic calculation does not evaluate a project's absolute value but rather its contribution to collective wellbeing, compared to a situation in which the project would not have been undertaken. This assumes that sector-by-sector reference scenarios are available, describing the evolution of main parameters (economic, technological and social trends) in the sector under consideration, along with a baseline option, that is a description of alternatives in the project's absence. The gains a project provides therefore very much depend on the hypotheses adopted to describe the situation in which it is not undertaken.

The importance of the reference scenario may be illustrated by the example of a railway project whose benefits in terms of carbon emissions reduction require evaluation. Such gains are essentially due to a modal shift. To appraise them, the evaluation sets a value on avoided emissions from users who switch from road or air travel to rail travel, using the shadow price of carbon path. However, the gains crucially depend on the assumptions made in the reference scenario about the car population from today to 2050 on. If the car population has not been decarbonized, the project provides major carbon gains via the modal shift. If, on the contrary, the car population is assumed to be fully electrified over the period, there will be no carbon gains at the end of the period, whatever the shadow carbon price happens to be (assuming that electricity itself is totally decarbonized). The railway project's advantages with regard to the reduction of carbon emissions due to the modal shift from car to train are therefore zero after 2050. The only gain left has to do with the shift from air to rail. Therefore, an increasing carbon value over the long term does not automatically translate into an increasing valuation of a project's carbon gains, in particular at distant time horizons. Everything depends on the reference scenario under consideration.

In current socioeconomic practices in France, reference scenarios and options are scenarios of convergence towards the official decarbonation goal (Net-Zero emissions in 2050), under the hypothesis of an alignment of public polices to achieve such goal. However, as the choice of the reference scenario is of crucial importance for the appraisal of projects, it may seem prudent to evaluate the risk that the decarbonation goal will not be achieved at the specified horizon, and to take into account this risk in the evaluation process. The analysis of a project's contribution to decarbonation must therefore take into account the speed of decarbonation. If decarbonation is slower than anticipated, the relevance of the project may be very different than if decarbonation is actually achieved in 2050. Assessing this risk necessarily requires expert judgements. For transparency, the good practice could be to use two reference scenatios, a "high" scenario – where CBA aims at assessing if the project contributes to reach the objective in an efficient way - and a "low" scenario – where CAB aims at assessing the contribution of the project to the decarbonation path.

3.4 Distributive issues

Cost-Benefit Analysis provides a synthetic appraisal of the opportunity of a project or a policy, under the hypothesis of simultaneous implementation of proper transfers to distribute the surplus (Drèze and Stern, 1987). In practice, however, the tendency is to act as if this question of the surplus distribution could be left to general income redistribution, which is justifiable only when costs and benefits are naturally distributed among all agents. In the case of environmental policies in general and climate policy in particular, this assumption is questionable: as a general rule, climate policies are regressive, and affect poor and vulnerable populations more than proportionally. Thus, CBA should also clarify the impact of policies and projects on the different categories of agents.

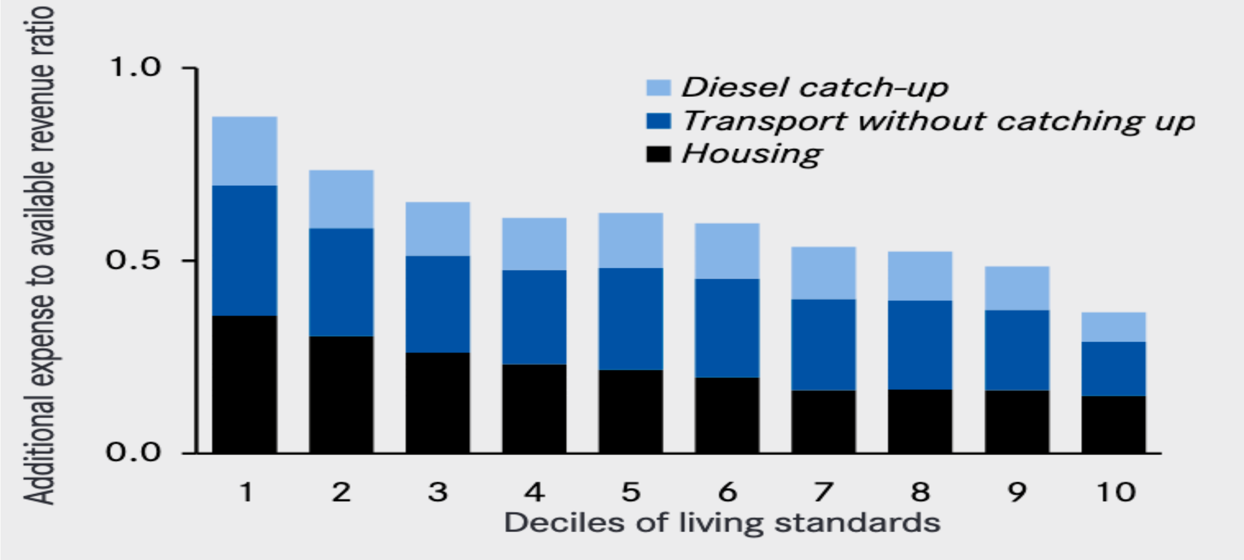
Let us take the example of carbon pricing in France. The French carbon tax, called "climate-energy contribution", is an excise duty applied to the CO_2 content of energy. It was introduced in 2014 at the initial rate of €7 per ton of CO_2, on the top of the domestic consumption taxes on energy products. It is paid by households for around 60%, and by firms for the rest. It generated a revenue of €6.4 billion in 2017. In 2017, the government announced an acceleration of the tax trajectory in order to reach 86.2 €/tCO_{2e} in 2022. In 2018, the carbon tax was thus increased from 39 to 44.6 €/tCO_{2e}. It was due to increase to 55 € in 2019, but the government decided in November 2018 to freeze the tax rate at 44.6 €, as a response to the "yellow vests" protest.

Bureau et al. (2019) examine the distributive impacts of the reform consisting in an increase in the carbon tax from its current level (44.6 €/tCO_{2e}) to the level expected to be reached in 2022 (86.2 €/tCO_{2e}), accompanied by the catching-up of the tax on diesel to the tax on gasoline by 7.8 cents per liter. This corresponds to the sum of the increases initially planned for January 2019, 2020 and 2021.

This reform is first considered without any revenue redistribution mechanism. The impacts of the reform are evaluated for each decile of standard of living. Figure 3 illustrates the burden of the reform, broken down into three parts: additional expenditures on housing due to the carbon tax, additional expenditures on transport due to the carbon tax, and additional expenditures on transport due to the diesel-gasoline catching-up. The poorer the households, the higher their burden: nearly 1% of disposable income for the first decile compared to 0.3% for the top decile.

Thus, the reform is regressive ex ante. The regressivity is due to housing, more than to transport. The share in the cost ratio of diesel-gasoline catching-up is far from negligible, as this catching up also has a regressive effect. This regressivity, which reflects the structure of emissions and the weight of energy expenditures in the respective household budgets, requires accompanying mechanisms to ensure the equity of the reform and its political acceptability. This is what has been lacking in the establishment of the French carbon tax.

`Figure 3: Effort rate of households associated with the reform before revenue use, in %



Source: Bureau et al. (2019)

Simulations show that the unequal impacts of the taxation are not only due to the level of income (vertical heterogeneity). Within each income decile - the so-called horizontal heterogeneity - the impact of the tax on purchasing power is significant. Among the households belonging to the first decile, 10% lose more than 220€ in purchasing power per year and per consumption unit with the implementation of the reform, while about 10% of households are not affected at all. Horizontal heterogeneity increases with income, so that in the 10th decile, 10% of households lose more than 480€ in purchasing power per year and per consumption unit, while 10% of households lose less than 25€. This intra-decile heterogeneity is due in particular to the location of households and the type of equipment they own: oil or gas heating *vs.* electric heating, diesel engine *vs.* gasoline. For example, for a given income, the relative loss of rural households compared to households in the Paris agglomeration is significant, around 130€ on average per consumption unit.

But a more in-depth analysis shows that horizontal heterogeneity is better explained by the equipment than by the geographical location alone. Once the differences in equipment are taken into account, the differences in losses between rural and urban households vanish: with equal income and equipment, a rural household loses 20€ more than a Parisian one, per consumption unit. On the other hand, for the same income and type of location, a household equipped with a diesel car loses 230€ more per consumption unit over one year than a household without a car, while a household heating on domestic fuel loses 157€ more than a household heating on electricity.[9]

The redistribution of carbon tax revenues is necessary to better share households' efforts, but its implementation raises a series of difficulties. It is relatively easy to redistribute revenues according to income, but much more difficult to take into account the dimensions of horizontal heterogeneity in order to properly identify losers without creating overly complex arrangements, significant windfall effects or a weakening of the price signal. The previous exercise suggested calibrating the redistribution of revenues according to equipment. But it would be both complex regarding the information to be collected, and environmentally counterproductive. Another –still imperfect– option, would be to subsidize equipment changes. This makes it possible to target some losers of the reform (those with polluting equipment) and does not decrease the incentive power of the tax. But it also has several disadvantages: it can create significant windfall effects, it can be regressive and, above all, it does not compensate all the losers. A last possibility would be to base the redistribution of revenues on geographical location, clearly correlated to equipment, although not perfectly.

Bureau et al. (2019) study different redistribution schemes, under the constraint that the combination carbon tax/revenue redistribution should reduce to a minimum the number of losing households in the first five deciles, and taking into account two crucial dimensions: household income and location. They show that it is actually possible to design such a redistribution scheme.

The 2018 "yellow vests" riots in France against the increase of the carbon tax showed how much attention should be paid to its distributive effects. But this is not specific to this instrument. Although the decarbonation of transport and housing could be designed to benefit people in fuel poverty, it is not spontaneously the case. Most of the instruments of climate policies are regressive, even more than carbon pricing: green subsidies are basically used by rich people (on tax credits, for example, see Borenstein and Davis, 2016) and the cost of emissions standards for new vehicles is more easily borne by these ones. The only difference is that this is often less visible than a tax.

Thus, we need to design efficient and equitable policies. Efficacy is the purpose of CBA. But the data needed to estimate the aggregate net social value are the disaggregated surplus impacts on the different agents and on different types of households. So implementing CBA is the best way to address the two ovjectives, in fact the only one to avoid confusion between the two, to properly target the measures, and to alleviate dilemma between equity and efficiency.

Conclusion

In order to achieve the "Net-Zero Emissions" goal, it is first of all necessary to define a relevant roadmap of the key policy actions and investments to be carried out. For that purpose, a common shadow price of carbon and an appropriate cost-benefit analysis framework are the two ingredients to be used to define the merit order of the mitigation actions.

Thus, establishing a shadow price of carbon at the European level is crucial to embody the climate ambition of the European Green Deal, to make global goals credible, to assess the climate impact of public investments and more generally to align policies and order mitigation actions according to their costs and merits. Such shadow price of carbon should form part of a global assessment framework defining also the reference scenarios and discount rates.

Good CBA governance is of great importance. CBAs must be assessed according to scientific criteria. They must specify what was not possible to be quantified, aspects related to distribution, and detail the way in which scientific uncertainty has been taken into account. The certification of assessments and the manner in which public or institutional debates can employ them are crucial for their use in the decision-making process. Upstream, the critical factor in the development of CBA for environmental regulations has generally been a legal obligation to do it. If such general legal framework exists, climate laws have only to ensure that all policies will be submitted to the carbon value. If it is not yet the case, they must primarily create this obligation.

It is also necessary to select the relevant mix of policy instruments to launch the relevant actions. In the policy world, the use of combinations of multiple policy instruments is common. Quite large numbers of measures encouraging decarbonation often accumulate for a given use. For example, energy efficiency and pollution standards, the bonus-malus system for acquisition of new vehicles, fuel taxation, and congestion charges all combine to reduce emissions from private vehicles. Such accumulation is not a problem in itself, as each measure targets a specific incentive at the time of purchase or use. We still need to have an aggregated view of incentives and obligations deployed and make sure that the accumulation of measures is enough, and that the implicit cost of compliance with standards is not too high for all or some of the actors concerned. Selecting the "best" combination of instruments requires painstaking work and involves art as well as science.

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