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# Well-being in the Context of Policies for Climate Change

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*DRAFT*

## **Summary**

This paper explores the challenges of climate change policies, emphasizing their uncertain effectiveness and acceptability. It highlights the need for interdisciplinary approaches that consider economic, social, environmental, and geopolitical consequences. While GNP is useful, well-being measures at individual and community levels are equally important. The paper stresses that policies must be socially equitable, as demonstrated by the “Gilet Jaune” protests in France. Effective climate action requires balancing financial and non-financial factors and addressing unintended consequences such as job losses. Ultimately, a multifaceted, inclusive approach is necessary to achieve sustainable and socially responsible outcomes in combating climate change.

**Key words:** climate change, equity, fairness, well-being, responsibility, action, inaction

**JEL:** H, I31, Q54, Q56

# 1. Navigating climate change and sustainability: A holistic approach<sup>1</sup>

## Towards Sustainable and Equitable Climate Policies: A Multidimensional Approach

We address the complexities of combating climate change, emphasizing that while many policies exist, their effectiveness and acceptability often remain uncertain. This highlights the challenge of *measuring and managing* external costs and societal constraints, such as energy, materials, greenhouse gas (GHG) emissions and government budgets. Anthropogenic GHG emissions, including carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O), are primarily the result of fossil fuel extraction and consumption, including coal, oil, and natural gas. In 2023, CO<sub>2</sub> emissions reached a record high of 37.4 gigatons, marking a 1.1% increase alongside global GDP growth of 3%, according to the International Energy Agency.

Effective policies require interdisciplinary collaboration and must consider both financial and non-financial dimensions. An interdisciplinary approach entails a *consequentialist* perspective, recognizing the broad spectrum of outcomes that any policy may produce—economic, social, environmental, as well as national, international, and geopolitical. Gross National Product (GNP) is a useful metric but should be complemented by *measures of well-being* at individual and community levels.

The acceptability of climate policies is crucial and hinges on comprehensive analysis and stakeholder engagement. Historical examples, such as the “Gilet Jaune” movement in France, demonstrate the resistance that can arise when policies are perceived as unfairly burdening certain groups, particularly lower-income individuals. We underscore the need for policies that are not only economically viable but also socially equitable, with particular attention to the well-being of the most vulnerable populations. Well-being must be viewed comprehensively; for example, job losses resulting from policies aimed at reducing emissions can be an unintended but significant consequence.

Ultimately, we advocate for a multifaceted approach to climate change that integrates technological, economic, environmental, and social dimensions. Policies must be well-understood and accepted by all stakeholders through analysis and community engagement. This approach aims to achieve sustainable and socially responsible outcomes, enhancing the likelihood of successful action against climate change.

### Brief Historical Context

The effects of nature's “excesses” have long been a subject of discussion. Svante Arrhenius was the first to describe the impact of CO<sub>2</sub> on global temperatures—though in Sweden, a warmer climate was initially seen as beneficial. Historically, deforestation has sometimes been justified in the colonies due to “excessive rainfall”. Even great scientists like Francis Bacon once feared that Earth's temperature would drop due to the cooling of internal magma.

While climate change issues have been recognized for decades, significant awareness only emerged after World War II (see the early warnings of the Club of Rome in Meadows, et al. 1972). Despite numerous proposed policies, humanity remains uncertain about the best course of action to address climate change. Stern (2007) argues for immediate action to mitigate the economic impacts of climate change. Yet, many people continue to demand more scientific

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<sup>1</sup> This paper originates from a three-day symposium held in Munster, France (June 12-15, 2024), focused on well-being and climate change. It summarizes our discussions and insights. The interdisciplinary team comprised scholars from economics (public, welfare, industrial organization, political economy), law, philosophy, and physics, alongside business representatives. The main findings from three parallel sessions were presented at the second AICC conference at the European Parliament on June 17, 2024 (see AICC, 2024).

proof before committing to decisive action, while others deny or minimize the scientific evidence (see Rich, 2019).

Nordhaus (2008) presents the DICE model, a framework for evaluating global warming policies. Though models offer simplified pictures of reality, they can serve as useful decision-making tools. At some point, like in a courtroom, we must make decisions based on reasonable confidence rather than waiting for absolute certainty.

### The Complexity of Climate Change Action

Concerns about rising global temperatures gained momentum in the 1980s, driven by successes like the Montreal Protocol, which addressed CFCs (chlorofluorocarbons). However, combating climate change has proven far more complex than resolving the ozone crisis, largely because of its long-term timeline and global scope. The relationship between these two struggles (Ozone and climate change) in the USA during the 1980s is explained well in Rich (2019).

While Europe and the USA have managed to reduce national emissions, overall global emissions continue to rise, driven primarily by economic and demographic growth in developing countries. This growth is not inherently catastrophic but does complicate efforts to combat climate change. Difficult trade-offs and compromises will be necessary.

Policies addressing climate change can be broadly categorized into six key areas: technical, governance, social, legal, regulatory, and behavioural approaches. Many argue for a “wait and see” approach, hoping for future technologies like carbon capture or fusion energy to offer solutions. However, this passive stance is unwise and irresponsible. The central question remains: can humanity continue its current economic growth trajectory with a growing population, or is a drastic change inevitable?

Developed nations cannot ask developing ones to forgo economic progress without offering viable alternatives. The true goal should be to reconcile economic growth, human welfare, and ecological sustainability—often referred to as the “One Earth” approach. No real progress will be made if environmental protection comes at the expense of human well-being, mobility, and economic development, and vice versa.

### The Trade-offs of Green Energy

The discovery of fossil fuels was initially hailed as a breakthrough, significantly improving global well-being. Over the last half-century, however, we have come to understand their negative consequences, including greenhouse gas emissions and local pollution. Green energy offers new hope, but we risk merely shifting from dependency on fossil fuels to reliance on rare earth elements and critical metals.

Mining for these materials often takes place in developing nations, where weak regulations lead to major environmental harm and human rights violations. This shift also increases reliance on countries like China, which dominates the rare earth supply chain, allowing wealthier nations to enjoy a “cheaper” green transition. The extraction of these resources is energy-intensive, often exacerbating the very problems green technologies aim to solve. According to Pineau (2023), five reasons drive the energy transition: “the environment, the economy, global peace, quality of life, and health”. These reasons should also resonate with climate sceptics.

The Draghi report (2024) highlights how developed nations (and especially Europe) have outsourced the environmental and human costs of this green transition to the Global South, where extractive practices cause significant harm. These externalities make the transition appear cheaper in wealthier countries while increasing inequality worldwide.

The laws of thermodynamics remind us that energy is finite, and its extraction and use are subject to increasing costs and difficulties. Transitioning to sustainable growth will not be easy or without suffering. Economists often discuss “high transaction costs” but rarely study the non-monetary suffering that may accompany these transitions.

### Well-being and Climate Policy

In this paper, we highlight the concept of well-being, arguing that it is critical to policy acceptability, both for consumers and firms. Well-being has local and global dimensions, immediate and deferred impacts, and is deeply intertwined with cultural contexts. Whatever actions we take—whether ignoring climate change or drastically reducing consumption—will inevitably impact well-being. Economists have struggled to incorporate well-being into climate change analysis, in part because it is difficult to quantify and lacks a universally accepted index.

Moreover, while taxes and benefits can be calculated using elegant models, practical implementation often falls short. For example, compensating indigenous populations affected by mining might seem reasonable, but the practicalities—such as distributing cash fairly—are complex.

### Unprecedented Challenges

Most scientists agree that we are already experiencing the effects of climate change and that they will likely worsen. Various demand- and supply-driven policies have been proposed, but they often overlook natural resource constraints. The extraction of oil, rare earth metals, and other resources is becoming more energy-intensive and costly due to depletion and lower-quality reserves.

Transitioning to a more sustainable growth path will involve significant challenges, requiring deep economic and social changes. While some argue for continued economic growth, this belief must be supported with proof that such a transition is feasible within the constraints of natural resources. As Grandell et al. (2016, p.61) argue, “Solar energy projections presented in the IPCC Fifth Assessment Report do not seem to be realizable with the currently known technologies and metals resources.” Another view is that the main threat now is over-exploitation of carbon-based fuels rather than inability to extract enough of them.

Ultimately, achieving a sustainable future requires balancing economic growth, well-being, and environmental preservation. Policymakers must take into account non-market dimensions, as discussed by Nussbaum and Sen (1993), and address inequalities in the transition to green energy.

There is still reason to hope for a better world, but the future is uncertain. Green technologies, while promising, have their limitations. For instance, in some countries, driving an electric car may produce more CO<sub>2</sub> than a conventional vehicle due to the energy mix (de Palma, Lindsey, Riou, 2023). Additionally, the shift to green energy, which requires significant natural resources, is leading to new environmental and geopolitical challenges. The energy transition from fossil fuels to renewables is essentially a shift from one resource dependency to another.

In conclusion, while green technologies and policies hold promise, a realistic approach must acknowledge the physical limits of natural resources, the high costs of transition, and the need to ensure equitable outcomes. The road ahead will be difficult, requiring global cooperation and difficult trade-offs, but the alternative—inaction or poorly planned policies—will likely lead to far worse outcomes for humanity and the planet.

## Outline of the paper

The issue of well-being is complex, yet we believe it is crucial for anyone seeking solutions to the climate crisis. No magic formula can encapsulate the joys and sorrows of humanity, and no financial compensation can console parents who have lost their child. Nonetheless, we must move forward and find solutions—an imperfect yet thoughtful policy is preferable to continuing as if nothing is wrong (BAU). Our stance is that no one can address the question of well-being from an ivory tower. We are attempting to piece together a puzzle, whose components fit together with difficulty, and are held by specialists in public economics (section 2), historians and philosophers (section 3), engineers (section 4), political economists (section 5), legal scholars (section 6), business representatives (section 7), and urban planners (section 8). Representatives from these various fields have contributed to this article.

Section 2 summarizes classical ideas addressing the following questions: What is well-being, how do we measure it, and how is it applied? Section 3 tackles the issue of responsibility, confronting those accountable for and those impacted by climate change—who are often not the same. Section 4 discusses the technological foundations (this technology can be examined, including under the hood of a car). Section 5 raises the question of coordination among actors who share a common goal but also wish to protect their own interests. Section 6 examines the effects of transitioning from fossil fuels to renewable energy on industries and workers. While renewable energy technologies have advanced, the transition presents risks like job losses, stranded assets in fossil-fuel sectors, and financial instability, complicating policy acceptance due to concerns about fairness and economic inequality. Section 7 examines the impact of solutions on businesses and, consequently, on workers and their quality of life. Section 8 brings us back to the here and now, addressing the challenges of concretely applying directives or broad principles to a heterogeneous population (due to geographic location, among other factors) and the issue of public policy and legislation acceptability.

This exercise could merit a book; here, we have provided a brief reflection that raises more questions than it solves. If we have any merit, it is in framing the issue of well-being from multiple perspectives, which must be brought into greater dialogue within academia, represented here, and also in the real world. May this reflection inspire other researchers to continue along the path we have sketched out.

## 2. Measures of country stability and of individual well-being: A public economics approach

The ultimate goal of climate change policies is to maintain or increase future well-being compared to a scenario where no action is taken. However, it is becoming increasingly evident that achieving this long-term objective will require some short-term sacrifices in well-being (Pisani-Ferry and Mahfouz 2023). Accurately measuring current well-being is therefore crucial to ensure that the climate transition remains tolerable as well as equitable, particularly in terms of who bears the associated costs. What tools are available to measure the evolution of well-being, and which are the most suitable?

The most common indicator used to measure a country's prosperity is Gross Domestic Product (GDP) and its micro-level counterparts, such as living standards or purchasing power. GDP measures people's access to marketed products and services, in a way that is supposed to represent their preferences over these goods: an increase in GDP suggests that people prefer their new economic situation over the previous one. In theory, GDP can therefore serve as an indicator of the monetary component of a population's well-being. In reality, several issues qualify this connection.

First of all, GDP is an aggregate measure that provides no insight into income distribution and may not align with the economic circumstances of individuals or segments of the population. By construction, GDP growth indeed weights each individual's growth rate by their income share in the population (Aitken and Weale 2020; Germain 2023). As a result, GDP is a “plutocratic” measure, where the growth of higher-income households counts more than that of lower-income households. Two approaches can be combined to address this. The first is to analyse growth incidence curves (Ravallion and Chen 2003), which provide a more detailed picture of income growth distribution. However, these curves alone do not provide any criteria for making decisions, for instance when having to choose between policies that affect the economic situation of different types of households differently. The second approach, useful in such cases, is a synthetic one that sums individual growth rates using meaningful aggregation rules, for instance, an unweighted arithmetic average, which avoids the bias toward higher-income households, or a weighted average, which puts less weight on the growth rates of the highest earners. Such meaning can arise either from a social welfare perspective - accounting for inequality aversion - or from the aim of having an aggregate measure that reflects the average growth experienced by the population.

A second issue of GDP as a measure of monetary well-being is that it only takes into account variations in income and prices. All other channels that affect people’s economic situation without translating into price or income signals are ignored. For that reason, rather than measuring “monetary well-being” in absolute terms, GDP measures the extra monetary well-being obtained through income, given initial conditions depending on the circumstances. If these conditions become less and less favourable because of climate change, leading to rising expenditures on damage mitigation, GDP could very well increase even though monetary well-being does not. For instance, if climate change leads to more forest fires and additional income is allocated to fire suppression, the discretionary income left for other consumption - the one that contributes to well-being - may decrease. These constrained expenses can also come from regulation policies addressing climate change. For instance, a ban on fossil fuel cars would not necessarily translate into a price signal, although it would be perceived as a cost by households if alternatives like electric cars are more expensive. These sources of bias are difficult to address in the routine production of GDP indicators. However, analyses using econometric techniques (Hausman 2003) can be employed to supplement traditional measures and quantify the extent of these biases.

But even should GDP be a perfect measure of monetary well-being, it would still remain a very partial indicator of overall well-being, as it overlooks many of its other dimensions. How can these dimensions be synthesized into a more comprehensive measure? Dashboards (Creutzig 2022), which track multiple factors influencing well-being, provide valuable information. However, they are not helpful for making decisions between policy alternatives that affect differently various aspects of well-being, since they do not hierarchize information.

One first solution for synthesizing information is the use of composite indices, the most famous one undoubtedly being the Human Development Index (HDI). Its construction is based on an unweighted geometric mean of three subindices reflecting three components of well-being: income, health, and education. While the HDI is transparent and easy to understand, it involves arbitrary choices in aggregating these dimensions (Ravallion 2010), with implicit assumptions on preferences over these dimensions that may not align with people’s actual preferences. As a result, the HDI could increase even if people feel their overall well-being has declined.

An alternative solution to avoid this problem is the subjective well-being approach, where individuals rate their living conditions, for instance, on a scale from 1 to 10. Since this approach provides a direct measurement of well-being, it is not necessary either to dissect its components

or to know anything about how individuals aggregate them. However, one major problem lies in the fact that people have different ways of translating their well-being into a number between 0 and 10, making it difficult to compare the results across individuals. For instance, an individual A may rate their life less favourably than B rates theirs, even though A would not accept trading their position for B's. Moreover, individuals' self-assessment scales can change over time, which complicates the use of subjective indicators for tracking the evolution of well-being across different periods.

Finally, the 'equivalent income' approach offers a solution to both the arbitrariness issue and the heterogeneity in self-assessment. It involves setting reference values for various dimensions of well-being (for instance, perfect health or ideal social connections), and then asking individuals how much income they would be willing to sacrifice to attain these reference conditions. Equivalent income, which serves as a measure of well-being, is then defined as actual income minus the amount one would forgo. Though it is expressed in monetary terms for practical reasons, it can incorporate any dimension of well-being. Importantly, it respects each individual's personal preferences and the results can be compared across different individuals and periods (Fleurbaey and Blanchet 2013), even if preferences are heterogeneous and change over time. The figure below is an illustration of the method in the case of two individuals, A and B, and two dimensions—income and an environmental factor, for instance, a climatic hazard such as the number of heatwaves per year.

The black curve is A's indifference curve, showing all combinations of income and environmental conditions that provide A with the same level of well-being as their current situation (marked by the black dot).

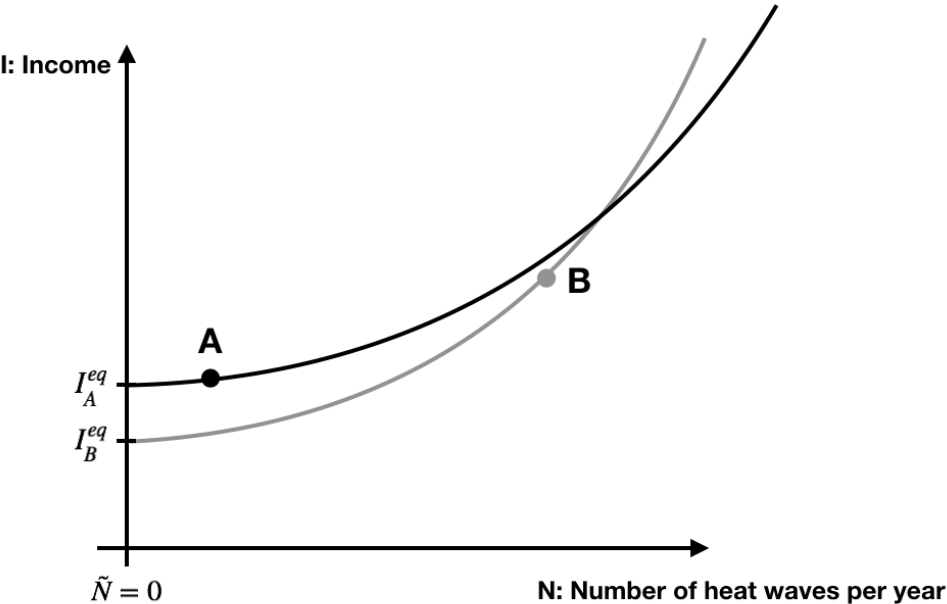


Figure: Indifference curves for two individuals, A and B, and two dimensions

Similarly, the grey curve is B's indifference curve and their actual situation is the grey dot. Individual B has higher income but experiences more frequent heatwaves than individual A, so it is unclear which one is better off. Computing their equivalent income using a reference scenario with no heatwaves provides an answer: individual A is better off, because individual



B would be willing to sacrifice a significant portion of their income to avoid heatwaves. Although the result depends on the choice of the reference value, selecting 0 climatic hazards as a benchmark seems reasonable as it represents an optimal scenario that everyone would prefer. This logic can be applied across other well-being dimensions to select appropriate reference values for each of them.

In the end, given that climate change and climate transition policies will (i) affect all dimensions of well-being and (ii) impact all countries around the world, each with its unique characteristics and preferences, measuring well-being through the equivalent income approach emerges as the most compelling solution. Since the method allows for interpersonal comparisons, it can be used for measuring inequalities and thus for making sure the climate transition is carried out fairly. In theory, this method requires explicit knowledge of people's preferences across various dimensions of well-being. In practice, these preferences can be estimated by regressing subjective well-being measures from different countries against objective data on various aspects of quality of life (Boarini et al. 2015), which may, however, be subject to endogeneity issues, or by using a mix of data on stated preferences (through dedicated surveys of willingness to pay for quality of life) and revealed preferences.

De Serres and Murin (2014) applied the equivalent income method to assess the effects of climate transition policies on well-being. They examine the impact of policies aiming to reduce emissions by 50% by 2050 across eight geographic regions, by including two dimensions of well-being: the negative impact of these policies on GDP growth, and the gains in life expectancy due to reduced emissions. They find an overall positive impact on equivalent income for the USA and an (almost) neutral effect for Japan, Australia, New Zealand, and Canada. For other regions such as Europe, the well-being increase induced by the gains in life expectancy is insufficient to offset the negative impact on GDP growth.

While their results do not lead to any definitive conclusions—as the study focuses solely on life expectancy and neglects other dimensions of well-being that could be positively impacted by the transition—the methodology and the practical feasibility of implementation are compelling. Future, more refined versions of their work should be undertaken and could provide a foundation for developing international agreements and national policies that allocate transition costs as equitably as possible, both within and among countries.

### 3. Prices, incentives and regulation versus social responsibility. A historical approach

In this section, we examine the notion of responsibility within the context of climate justice, focusing specifically on how to frame individual responsibility for climate change. We argue that the current reliance on backward-looking responsibility, predominantly grounded in distributive justice principles like the Polluter Pays Principle and the Beneficiary Pays Principle, is inadequate. While these principles are foundational in climate policy, they lead to significant inefficiencies in both fairness and climate mitigation outcomes (Lippert-Rasmussen 2015). Therefore, we propose a shift toward a more prospective, forward-looking approach to responsibility that better addresses the complexities of climate change.

#### Climate Justice and the Distribution of Responsibility

The climate crisis, though a global and collective challenge, disproportionately impacts vulnerable populations due to disparities in access to resources, geography, and life opportunities. As a result, climate policies must ensure that the worst-offs are not further burdened, which requires a focus on equity. Achieving fairness and social acceptability in climate policies is one of the greatest challenges of the 21st century (Gupta 2019). In response

to growing structural inequalities, both between and within countries, climate justice has emerged as a key focus in climate discourse, aiming to align climate action with principles of equity and fairness. It encompasses two primary objectives: (1) mitigating the impacts of climate change and (2) the fair allocation of responsibilities related to both climate action and burden-sharing.

However, a central issue in this debate is the question of framing and addressing responsibility. As Jamieson (1992) suggested, climate change presents a unique problem: “the possibility that the global environment may be destroyed, yet no one will be responsible”, as it is a systemic issue, diffuse across space and time, where “apparently innocent acts can have devastating consequences” (Jamieson 1992, p.149). Given the collective and unintentional nature of many climate-related actions, it becomes challenging to hold any individuals responsible. Nonetheless, some theorists, like Young (2011), argue that all individuals involved in unjust structural processes share a responsibility to change them, even if they did not directly cause harm. However, assigning responsibility for actions beyond an individual’s control is contentious. Knight (2009) and Stemplowska (2008) argue that not holding people accountable for actions beyond their control can be more inequalitarian and unjust than holding them responsible. Therefore, it is essential to critically examine how responsibility is framed in climate policies.

In theories of distributive justice, responsibility is often tied to the concept of luck egalitarianism<sup>2</sup>, which asserts that individuals are responsible for their choices and the consequences that arise from them, as long as no external factors constrain their decision-making. This framework has significantly influenced how climate responsibility (IPCC 2014) is understood. As Swyngedouw and Heynen (2003, p.910) noted, the environmental justice movement fundamentally embodies a liberal and distributional perspective on justice, where justice is interpreted through the lens of Rawlsian fairness (Caney 2009; IPCC 2018). Therefore, in the context of climate justice, responsibility is often framed in a backward-looking, causal manner, where individuals or nations are held accountable for their contributions to greenhouse gas (GHG) emissions based on their past actions. The Polluter Pays Principle (PPP) and the Beneficiary Pays Principle (BPP) are two key distributive justice principles that embody this causal framework. The IPCC (2014) supports this view by stating that human activities, particularly industrial processes and consumption patterns, are the main drivers of climate change. This anthropogenic nature of climate change raises significant justice concerns, as the most vulnerable populations—those with the least responsibility for GHG emissions—are often the most affected by climate impacts. The PPP and BPP aim to address this imbalance by making those responsible for emissions, or those who benefit from them, bear the costs of climate mitigation and adaptation. However, these principles face considerable challenges. The Polluter Pays Principle, for instance, assumes that polluters can be easily identified and held liable. Yet, many past emitters of GHGs were unaware of the harmful environmental impacts of their actions, raising questions of fairness. As Caney (2005) points out, it is difficult to hold individuals responsible when they were justifiably ignorant of the consequences of their emissions. Moreover, the temporal gap between the emission of GHGs and their environmental effects complicates matters and the establishment of the causal attribution of responsibilities, as GHGs remain in the atmosphere for centuries. It therefore raises issues of intergenerational responsibility, making it challenging to assign liability solely based on past actions. Many of those responsible for historical emissions are either no longer alive or were unaware of the future consequences of their actions, making it unjust to hold them

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<sup>2</sup> Luck egalitarianism is not a homogeneous theoretical field; rather, it encompasses a variety of perspectives and alternatives regarding responsibility. See Dworkin (1981), Cohen (1989), Arneson (1989), Roemer (1993), Anderson (1999).

responsible. Furthermore, applying the Polluter Pays Principle to individuals in developing countries could exacerbate existing global inequalities. Many developing nations rely on polluting energy sources because they lack viable alternatives. Holding them accountable for their emissions without considering their economic and social constraints could hinder their development and exacerbate poverty. Shue (1993) highlights this issue by distinguishing between “luxury emissions” and “subsistence emissions”—the former being emissions from nonessential activities, while the latter are necessary for survival. Requiring poorer nations to pay for emissions related to basic needs would likely push them below a decent standard of living, contradicting the principles of justice and fairness.

Similarly, the Beneficiary Pays Principle faces limitations. While it seeks to hold those who benefit from emissions accountable, it does not always account for disparities in wealth and power. For instance, a person may benefit from emissions but still live in poverty. Applying the BPP in such cases could unfairly burden individuals who are already disadvantaged, further perpetuating inequality. This raises the question of whether benefiting from emissions is sufficient grounds for assigning responsibility, particularly when it would compromise an individual’s standard of living.

Moreover, taxation in environmental economic policy is traditionally used to discourage harmful behavior from consumers and producers, but it often displaces individual responsibility by focusing solely on economic incentives, leading to a certain crowding-out effect regarding responsibility. Ballet et al. (2004) argue that responsibility can be defined independently from taxation, and that fostering a high degree of responsibility could serve as an alternative to taxation.

### [The Limitations of Backward-Looking Responsibility](#)

The reliance on backward-looking responsibility, which focuses on past actions and decisions, presents several limitations in addressing the complexities of climate change. First, it tends to prioritize the attribution of blame and punishment over constructive solutions, diverting attention from identifying underlying structural issues or implementing measures to prevent future harm. By focusing on past actions, backward-looking responsibility often fails to account for the need for proactive, forward-looking solutions, which are critical for tackling environmental challenges like climate change. As Fleurbaey (2012) argues, luck-egalitarian theories of responsibility tend to develop a “pre-institutional” conception of responsibility that focuses too heavily on individual actions and outcomes, rather than on the social relationships and institutions that shape those actions. In the context of climate change, this approach is inadequate because it does not address the broader systemic and structural factors that contribute to environmental degradation. Responsibility should be understood as a forward-looking obligation to participate in collective efforts to prevent future harm, rather than as a backward-looking, punitive mechanism for assigning blame and ignoring individuals’ capacity to constrain themselves.

### [Toward a Forward-Looking Approach to Responsibility](#)

To address the limitations of backward-looking responsibility, we advocate for a shift toward a forward-looking, relational approach that emphasizes individual responsibility based on duties, shifting from responsibility for the action to responsibility of the agent (Ballet et al. 2014). This approach is rooted in the idea of relational egalitarianism (Anderson 1999; Hausman 2011; Strawson 1962; Schmidt 2022) and the social connection model (Young 2011), which acknowledges the interconnectedness of individuals and the moral duties they have toward one another (Scanlon 1998). Young states:

“A theory of personal responsibility in relation to justice ought to ask not only in what ways individuals are responsible for their own circumstances, but also in what ways we should understand ourselves responsible for the background conditions of others’ lives that are produced by structured institutional relations.” (Young 2011, pp. 39-40).

Rather than focusing solely on the distribution of resources or the punishment of past actions, relational egalitarianism emphasizes the importance of social relationships and democratic equality in addressing the root causes of structural injustice, such as climate inequalities. Relational egalitarianism challenges the asocial framework of luck egalitarianism (Arneson 2011) by recognizing that individuals are embedded in broader social, economic, and political structures. These structures not only shape individual actions and preferences but also contribute to systemic injustices, as observed in the context of climate change. Anderson's (1999) theory of democratic equality provides a robust foundation for moral responsibility toward others by emphasizing relational equality and mutual respect (Schmidt 2022). Unlike luck-egalitarian approaches, which focus on compensating for disadvantages arising from bad luck, democratic equality shifts the focus to social relationships and the elimination of oppressive hierarchies. According to Anderson, individuals are not simply isolated agents responsible for their outcomes; they are part of a democratic community where each person has a moral duty to ensure that others can participate as equals in social, political, and economic life. This perspective establishes moral responsibility as inherently forward-looking, grounded in the idea that each person must contribute to just social arrangements and to mitigate the structures that perpetuate inequality. Applied to climate justice, this approach suggests that responsibility for mitigating climate change extends beyond individual contributions to greenhouse gas emissions; it includes an obligation to transform unjust systems and ensure that vulnerable populations are protected and empowered to participate fully in the decisions that shape their lives. By focusing on collective moral duties and the need for proactive solutions, relational egalitarianism could offer a more comprehensive framework for addressing climate responsibility. Ballet et al. suggest a revision of the idea of the agency and state:

“Agents are defined, therefore, less by their capacity to make free choices than by their capacity for responsibility. Their choices are free only to the extent that they themselves are responsible. In this conception of responsibility, the causal relationship is replaced by a relationship of implication.” (Ballet et al. 2014, p.36).

Regardless of their socioeconomic status, individuals have equal moral worth and should have equal opportunities to participate in discussions about climate policies. This inclusivity is essential to ensure that marginalized voices, often disproportionately affected by climate change, are heard and considered in decision-making processes. A focus on democratic equality could foster a more just and equitable framework for our understanding of responsibility in climate change policies. Godard argues:

“Around the figure of the citizen, the contractualist tradition of political philosophy turns away from this consumerist vision of the general interest. The challenge is to discern the common good by leading each citizen to distance themselves from their personal particularities, which hold only private value, and to detach from their attachments and affiliations that individualize them. The object of collective choice is no longer the harmonization of individual consumption plans but rather the common interest of society as a whole. (...) Since the aim is no longer to assert individual differences, which each person knows best for themselves, but rather to present perspectives on the common good, the formation of a citizen's preferences requires their engagement in broad and extensive deliberation with others. It is through discussion with others that each person is led to recognize what constitutes the collective they form

and to discern on which rules and common projects they can agree, beyond their individual differences.<sup>3</sup>” (Godard 1999, p.25).

## Conclusion

In conclusion, while the Polluter Pays Principle and the Beneficiary Pays Principle have been instrumental in shaping climate justice discourse, they are limited by their backward-looking causal nature of responsibility. These principles focus on past actions and individual decisions, often leading to unjust outcomes and inefficiencies in climate mitigation. In this section we suggest that a forward-looking, relational approach to responsibility, grounded in the principles of relational egalitarianism, democratic equality and collective moral duties, provides a more equitable and effective framework for addressing the complexities of climate change. This approach not only fosters collective responsibility for future outcomes but also promotes proactive measures to prevent further environmental harm, making it a more suitable basis for climate justice in the 21st century. This discussion initiated a philosophical reflection on the concept of responsibility, proposing a new approach without specifying its practical application. Additionally, we could highlight the necessity for economics to better incorporate environmental ethics and the ethic of responsibility, as emphasized by Georgescu-Roegen with his entropy law (1971) suggesting that economic decisions must respect an environmental ethic that transcends distributive justice and acknowledges the long-term biosphere. Similarly, Jonas' “Principle of Responsibility” (1979) which asserts that individuals must act in ways that ensure the sustainability of human life on Earth, emphasizing ethical obligations towards future generations.

## 4. Towards Sustainable and Equitable Climate Policies: A Political Economy Approach

This section analyses the international and national policy making on climate change. It discusses the difficulty of reaching an international climate agreement and the translation of international commitment to local policies.

It is important to distinguish the political mechanisms that decide on adaptation issues from those that focus on mitigation (reduction in emissions). Adaptation is much more a local issue as its effects are generally limited to the country or neighbouring countries. Reducing emissions has local side effects (limiting local air pollution) but has mostly global effects on climate.

Decisions on mitigation can best be understood in a two-tier framework. The first tier involves commitments at the international level. The second tier calls for the implementation of the commitments at the national level.

At the international level, one decides on commitments to reduce climate emissions. As international agreements are not enforceable, the commitments are expected to be self-enforcing (Barrett 1994) and this generates insufficient efforts: In an illustrative example of this result with 10 identical countries, one ends up with a total effort equal to only 16% of the ideal level that balances costs and benefits at world level. However, we see larger commitments or pledges than one can expect from the self-enforcing levels. There are several complementary explanations for this. Barrett and Dannenberg (2016) analyse with an experimental game, the pledge and review process like the one used for the Paris agreement (2016). They show how, in controlled experiments, this process leads to higher targets and efforts than one could expect from a prisoner's dilemma viewpoint. One sees a lot of naming and shaming by green lobby groups in the preparation of the international conferences and their follow-up in the

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<sup>3</sup> Author's translation.

Conferences of the Parties (“COP”). Without these strong green actions focused on the international negotiation scene, one would see smaller mitigation commitments.

Battaglini and Harstad (2020) develop explicitly the two-tier approach to climate policy. In their theory, politicians negotiate international agreements in the presence of re-election concerns and leave the ultimate decision on compliance to the politicians who want to win the next elections. An international agreement is negotiated by one political party, but in the following election, the voters may be “green” or “brown”. Depending of the vote, the elected party decides whether to comply or not with the treaty. This implies that the party negotiating the agreement anticipates that, after the election, it may have to comply if the vote is green and will not comply if the vote is not green. This explains why, in equilibrium, the green party designs an international agreement that can be enforced if it is re-elected, and similarly, the brown party negotiates an international agreement that allows them to escape enforcement if it is re-elected. Crucial in the results is the rent of staying in office after the elections. The larger this rent, the more the parties will try to differentiate themselves for the voters by complying when the election chooses a green party and by not complying when the election chooses a brown party. As both the depth of the agreement and the sanction determine the voting outcome, this can lead to strong agreements (all parties comply), weak agreements (where only the green party complies), ineffective agreements (nobody complies) and even overambitious agreements. This problem of indeterminacy is more likely to prevail in a democratic regime where the office rent is high and parties are polarized. The model exploits the fact that green policies now belong in major countries like the US and Australia as a contentious issue and not a valence issue that is a political issue where there is a broad consensus among voters and the political game among political parties is to compete on competence. Even in Norway, it is no longer the case. See the analysis of Farstad and Aasen (2023) for the election of 2021.

Of interest is also the role of national technology investment. In the first period, an incumbent government can invest in technology that reduces the cost of compliance in the second period. The green party will not necessarily reduce the cost of compliance to zero because then it can no longer differentiate itself from the brown party. The stake in being a leader in green technologies should not be forgotten and fuels the international race for public subsidies to support R&D in this domain (Electric car for China, IRA for the US).

At the second tier, the country level, implementation of a pledge requires concrete actions and policies. At the international negotiation level, the pledges for future efforts often lack a detailed cost-benefit assessment: most negotiating parties do not know what it will cost to go for net zero emissions in 2050. When costs and benefits are uncertain, long-term promises are easy. This will be different at the country level. Costs of implementation will be less obscure and the groups that will be required to take action and bear the costs will be identified: the yellow vests are a well-known example. Politicians prefer to postpone difficult decisions. Politically difficult decisions are decisions that are needed, have an important future benefit but need a lot of study and preparation, are unique and can fail. There are many examples of important political decisions that are postponed: delaying the retirement age, privatization of a public service, macro-economic stabilization. the implementation of a climate commitment also belongs to this category. Alesina and Drazen (1991) show how bargaining between different population groups over the sharing of the costs of macroeconomic stabilization leads to costly delays. It is a war of attrition: the costs of delaying the reform increase over time. Different groups have to share the cost of the reform and they all prefer a design of the reform that is less costly for them. Stabilization policy decisions will only be taken when the costs of waiting to agree become too high for one group and this group will give in and accept a design that is less favourable for them. When applying this theory to mitigation decisions, it is difficult to see that costs for

delayed action under the form of climate catastrophes are strongly increasing for a particular group in one country, postponement long in the future would be the expected political outcome.

Another interesting take on the climate policy issue is not to start from economic theory but to start from the opinions expressed in surveys at the level of population. This means trying to understand whether these opinions could be consistent with implementing a vigorous climate policy. To the surprise of the simple homo economicus thinking, there is widespread support for a Global Climate Scheme (Fabre *et al.* 2024). This global scheme consists of an international equal per capita allocation of tradable emission rights, complemented by a tax on the richest 1 to 5% in the high and middle-income countries. These figures might suggest the magnitude of associated international transfers is pretty modest. However, when we recall the order of magnitude of the largest benevolent international transfer in economic history, we can be more pessimistic about the feasibility of this transfer, which appears massive. The Marshall Plan dedicated an unprecedented amount of foreign aid—\$13.2 billion, over \$130 billion in today's dollars, or 5.2% of US GDP—to European countries to rebuild their war-shattered economies on a cooperative basis. It was a one-shot gift whereas the tax scheme favoured by the survey respondents should be in place for all the transition period, at least 25 years.

These opinions are based on stated preference (where actors are asked to make hypothetical choices in a controlled environment) surveys administered to 40,000 individuals from 20 high and middle-income countries and where sincerity of opinions is checked with complementary survey work. An important finding is that the population finds that this policy is best put in place at the global (international) level rather than at the local level. The international level would be a better guarantee of fairness and effectiveness.

These findings do not match with the revealed preference information (these are the preferences expressed in actual choices) on climate mitigation. The OECD computes for the high and middle-income countries an effective climate tax that includes tradable emission right policies and finds low effective taxes: ranging from 28 €/ton of CO<sub>2</sub> in the EU to 13 €/ton and 8 \$/ton in India (OECD 2021). How to explain the mismatch between opinions and political action? Fabre *et al.* (2024) see different reasons. First, there may be ignorance among policymakers regarding the support for the GCS. Second, people or policymakers may believe that globally redistributive policies are politically infeasible in some key countries like the U.S. or may be technically infeasible and therefore unrealistic. Finally, as policy is disproportionately influenced by the economic elites, public debate may be shaped by the wealthiest, who have vested interests in preventing global redistribution.

So far, we have considered negotiations between and within countries whose political system is a liberal democracy. According to the Varieties of Democracy Institute, 91 countries are labelled liberal democracies, which represent 29% of the world's population and 36% of the world's carbon emissions. The main bulk of Asian, Middle Eastern and African countries are largely autocratic. China and Russia alone represent the same amount of carbon emissions as those emitted by fully democratic countries.

In democratic countries, voices (Malm 2018) are being raised to suggest that democratic regimes will prove incapable of meeting their climate commitments and that only autocratic regimes will make it possible to achieve the targets set. In view of the pledges to meet the target of net zero carbon emissions by 2050, this enthusiasm for the authoritarian option seems misplaced. So far, the 131 countries pledged to achieve net zero produce over 87% of global carbon dioxide emissions. Among them, many liberal democracies have pledged to do it by 2050. Commitments towards later dates are insufficient to meet this goal. But some important countries have endorsed this objective. This is, the case for China and Russia (2060), for India

(2070). Iran and North Korea, and it is striking that only a few Arab countries have done it (Tunisia, Lebanon, UAE, Saudi Arabia, and Kuwait for 2060). The role of green activists is well established in international agreements, and most, if not all, of them come from democratic countries. It is likely that Muller's conclusion (2023) is correct. The best hope of curbing global warming still lies with democratic countries.

### Concluding comments

In conclusion, for mitigation, international agreements with naming and shaming remain a keystone of policy making. They act as an anchor point for national action. Moreover, climate action organized at the global level using tradable equal per capita allocation of permits and complemented by a redistributive tax seems to be acceptable for a large part of the population even if this does translate into national climate policy making and it is not clear why not.

Things are different for adaptation policies. Adaptation actions require four types of actions: public infrastructure to protect against calamities (fire, floods), regulation of private infrastructure decisions and third, help in the restructuring of economic activities, mainly agriculture, and finally, migration policies. There is growing evidence (Intergovernmental Panel on Climate Change 2022) that climate catastrophes force politicians to make costly public investment decisions even if their full benefit will only occur far in the future as catastrophes are probabilistic. They may still be too late but there is more hope for effective action.

## 5. The role of laws and law enforcement: A legal approach

The legal battle against climate change involves a complex interplay of principles, regulations, and enforcement mechanisms. This analysis explores the French legal system governing climate action, examining the challenges in implementing and enforcing laws designed to address environmental damages. Analyzing the legal questions surrounding actions to restrain climate change, this section examines foundational legal principles, sanctions, enforcement challenges, illustrative case studies, and democratic considerations in environmental policy-making.

Prima facie, the relevant law questions linked to actions to restrain climate change could be summarized in four items.

1) For lawyers, legal principles are necessarily linked to its implementation rules; principal and practical conditions cannot be separated, because the latter determine the strength, scope, and effectiveness of the rule of law. As a matter of fact, the implementation rules can lead the law to be more efficient, or, on the contrary, make it less effective or even delay its effects.

Two examples are worth mentioning: the first oil spills on the French Atlantic coast led the Maritime International Organization and the European Union to enact a mandatory law imposing that the ships carrying oil have a double hull, in order to reduce the risk of oil spills in the sea; but this new rule applied only to newly built ships. Needless to say, that this transition period means a lot of years before the new mandatory rule produces its effects.

Another example: after several international scientific studies had shown the harmfulness of neonicotinoids, two implementing European regulations (May,29,2018, n° 2018/783 and 2018/7585) forbade these products in the European Union with possibilities of exceptional derogations; consequently, two decisions by the French Ministry of Agriculture: the first one on February 5, 2021, and the second one on January 31, 2022, granted derogation, both of them, for 120 days- for beetroots. On May 3, 2023, the *Conseil d'État* (the highest administrative judge in the country) judged that these two decisions were illegal. But it was too late.



2) French law of August 17, 2015, on ecological transition and the 2015 Paris Agreement adopted at the end of the Climate Change Conference (COP 21) - the latter is unfortunately not directly applicable in France - are an expression of the proactive voluntary political actions needed by climate change.

However, these legal texts - main legal tools in the fight against climate change - only set goals to reach, without establishing clear legal duties; though firms have a duty of environmental vigilance (*Conseil Constitutionnel* n° 2011-116 QPC, Michel Z, 2011), this duty remains a very general one and, as a consequence, it is quite difficult to establish a violation of it. In other words, if the goals are clearly expressed, the binding tools to reach them do not appear clearly.

3) Each rule of law raises the question of its sanction: what is the punishment (in particular what is its degree) and in case of violation what is the probability of being discovered, and in case of violation punished? This entails two questions: (i) What practical system of control is organized to ensure the effectiveness of law and (ii) How will the judge behave: will he be concerned, severe (or not), act with strictness, etc.?

These questions are relevant not only for mandatory rules but also for incentive rules (how relevant is the incitement, what is its width, how does one avoid bargaining effects, and so on).

Regarding the environment, several behaviors are now considered as crimes, which of course creates a possibility of criminal punishment. However, experience shows that this type of punishment, which should in theory scare more, appears in practice to be quite hazardous, especially if one keeps in mind that getting a person convicted in a criminal trial is - fortunately - more difficult than in a civil case. This leads to consider that civil liability remains a more efficient tool to have environmental rules enforced - especially since the French law of August 8, 2016, which allows to ask (in court) for legal redress for environmental damages (articles 1246 (and subsequent) of French Civil Code).

Despite its flexibility, the medium constituted by the non-criminal liability suffers from defects due to the French organization of justice. For instance, though the French administrative courts became receptive to claims against the French State when the latter failed to act against climate change or air pollution, getting these judgment(s) into force requires sometimes several years. In a case where a French Non-Governmental Organization (NGO), *Les Amis de la Terre* sued the State for not taking the relevant measures able to respect the European air pollution limit levels, it took 10 years to get a judgment condemning the State to pay an amount of 10 million euros per semester for how long. While this amount is significant, it must be compared to the budget of the State.

Civil claims are also hampered by the extreme weakness of the French class action system, especially when compared to common law class actions. For instance, (i) the fact that no publicity of a class action is allowed until the *Cour de cassation*'s decision (French Supreme court) (i. e. 7 or 8 years after beginning the trial and around 12 to 15 years after the facts themselves), (ii) it is an *opt-in* system, which means that only the persons who expressly write that they intend to be claimants are considered as victims and (iii) it is impossible to condemn the firm who infringes the law to give back the entirety of the illegal profit, although this can be ordered in a lot of countries.

Even if things change slowly, European and French judges are now more receptive to environmental damages. Despite the importance of judicial decisions as symbols, trials are very few compared to all environmental infringements.

4) Elaboration and adoption of law rules about climate change also present a democratic issue, especially when there is a will that action against climate change should not worsen the situation of the poorest part of the population.

This raises another question: whether the administration is entitled (or not) to the monopoly to define what we call public interest or if it is necessary to associate the concerned people to the choice of new rules, of their setting and their scope, in order to establish a new type of governance. In France, the Environment Charter, which is considered as a constitutional rule, states the right of citizens to participate in public decisions having an impact on the environment.

The French code of environment underlines the importance of participation when it rules that it is necessary:

In order to improve quality and legitimacy of the law: (a) To ensure that a healthier environment will be preserved for present and future generations; (b) To educate people and make them receptive to the preservation of the environment; (c) And to improve and diversify information about the environment.

French law defines conditions for intermittent participation in future texts in specific sectors, leading to non-binding advices. On the opposite, law can implement in some cases a deliberative democracy, i.e., debates involving citizens invited to define a public policy with the aim of constraining climate change. This happened with the 150 French citizens chosen “to define structuring measures in order to reduce greenhouse gas emissions by 40 % by 2030 compared to the 1990’s level” (E. Philippe, letter from the Prime minister to the President of the *French Conseil Economique, Social et Environnemental* (CESE)). This experience was based on an interesting system, choosing citizens on several criteria (sex, age, diplomas, etc.) and this panel of citizens was informed by auditioning scientists over several months. One knows, however, that the government adopted only part of these Convention proposals. As a matter of fact, this Convention, invited by the President of the French Republic, remained advisory.

In conclusion, effectively addressing climate change requires a robust legal framework that integrates clear principles, enforceable regulations, proactive judicial oversight, and inclusive public participation to bridge the gap between ambitious goals and practical outcomes.

## 6. Technologies and social acceptability: an engineering approach

Combustion of fossil fuels is responsible for about two thirds of global anthropogenic greenhouse gas (GHG) emissions with CO<sub>2</sub> the main contributor. The share is even larger in the European Union and the United States. Despite efforts to curtail carbon emissions, they have risen since the COVID-19 pandemic and fossil-fuel emissions reached a record level in 2023.

Coal, oil, and natural gas are the primary fossil fuels. Coal is the most intensive CO<sub>2</sub> emitter on a unit-energy basis. Fossil fuels have long dominated energy use due to their advantages: high energy density, ease of storage and transportation, relative safety, and affordability. But fossil fuels have several disadvantages in addition to GHG emissions including local pollution and landscape scarring. Fuel prices are also volatile, which complicates production and energy usage decisions and contributes to macroeconomic fluctuations.

Fossil-fuel consumption can be reduced in several ways: by (1) improving the energy efficiency of internal combustion engines, heating and cooling systems, industrial processes, etc.; (2) reducing leakage and other inefficiencies throughout the supply chain from resource extraction

to final consumption; (3) curtailing energy-intensive activities; (4) switching to renewable energy sources (addressed below); and (5) preventing GHGs from entering the atmosphere, considered next.

### Carbon capture and storage

A significant fraction of anthropogenic GHG emissions is absorbed by natural processes. Nevertheless, carbon capture and storage (CCS) of GHGs is considered essential for meeting CO<sub>2</sub> emission reduction targets. A number of CCS methods are either in use or under study including: (1) reforestation and afforestation; (2) sequestration in soils; (3) bioenergy with CCS which captures and stores CO<sub>2</sub> released from biomass-based processes; (4) enhanced rock weathering; (5) ocean fertilization; (6) restoration of coastal wetlands; and (7) direct air capture and storage in which CO<sub>2</sub> is removed from the atmosphere. CO<sub>2</sub> can be captured from coal power plants, chemical plants, cement kilns, and other point sources.

CO<sub>2</sub> has long been used for enhanced oil recovery by injecting it into oil reservoirs. It can be used to produce fertilizer, fuel, and chemicals although unlike with enhanced oil recovery this offers only temporary storage until the product is burned or consumed. Long-term CO<sub>2</sub> storage is also possible in exhausted gas fields, exhausted coal seams, and saline formations.

Some CCS methods such as reforestation and soil sequestration provide co-benefits such as enhanced biodiversity and employment. By extending the lifetime of carbon resources, CCS can also prolong employment in fossil-fuel industries and reduce financial losses due to stranded assets. But CCS has several limitations and drawbacks. Constructing CCS units for power plants is costly, and the process of carbon removal and storage consumes an appreciable fraction of the energy produced by the plants. CCS does not remove particulate matter and other toxic gasses from the flue gas. The potential to use CO<sub>2</sub> to make products is small compared to the total volume of CO<sub>2</sub> emitted, and the products are likely to cost more than with other methods. Direct air capture is largely experimental and costly, and has yet to be demonstrated at scale.

### Renewable energy

Renewable energy sources are a linchpin for combatting climate change. They come in various forms and vintage. Conventional sources include hydro, geothermal, and nuclear. Solar and wind power have been progressing rapidly, and in some countries now account for a substantial fraction of total installed electricity generating capacity. Prospective renewable sources include ocean technologies (tidal, wave, and thermal) and hydrogen. The costs of several renewable energy technologies have fallen greatly in recent years. According to the IPCC, from 2010 to 2019, unit costs declined by 85% for solar energy, 55% for wind energy, and 85% for lithium-ion batteries. Thanks to learning curves, costs have fallen by about 20% with every doubling of global cumulative capacity and in many cases are now lower than the cheapest fossil fuels. Yet, despite substantial advances, all renewable energy sources have limitations and drawbacks.

*Availability:* Hydro, geothermal, offshore wind, and tidal power are both physically possible and economically viable only at a limited number of locations.

*Resource requirements:* Batteries and some other renewable energy sources require scarce materials such as lithium and cobalt that are found in only a few countries, some of which are undemocratic. Biomass and hydrogen energy are energy-intensive to produce. Power from solar panels and windmills needs to be connected to the electricity grid, sometimes over long distances. A distribution network is also needed to make hydrogen viable as a fuel for transportation. A fraction of the energy in the primary energy source is lost at each stage of

production (i.e., extraction, conversion, transportation, storage, and electricity generation) before it reaches the final consumer.

*Land use:* Solar panels and windmills occupy space that might otherwise be used for agriculture or other purposes. They may also contribute to habitat destruction, and when decommissioned may require costly reclamation.

*Intermittency and interruptions:* Solar power is available only during the daytime when the sun is shining, and wind power only when the wind is blowing at sufficient speed. Solar and wind energy can be stored in several ways (e.g., pumped storage and batteries) but storage capacity is costly and requires energy that itself may emit CO<sub>2</sub>. Renewable energy sources are also susceptible to prolonged disruptions. For example, in 2022 nuclear reactors in France were shut down for planned maintenance as well as emergency maintenance to address safety problems. Hydropower was also reduced following periods of intense heat and droughts.

*Environmental effects:* Windmills create noise, kill birds, and are sometimes considered visually intrusive. Biomass energy can generate local urban air pollution.

*Physical damage:* Solar panels are vulnerable to damage (e.g., from hail). Catastrophic events can also happen such as nuclear reactor failures (e.g., Fukushima in 2011) and dam failures.

*Institutional barriers to adoption:* Institutional barriers often impede the implementation of large-scale climate-change-mitigation measures. Barriers include a lack of financial incentives, problems with ownership, difficulties in choosing production sites, legal impediments, and complex licensing procedures.

Politics is another factor. Recent experience in the province of Alberta, Canada is illustrative. In 2022, three quarters of all new solar and wind projects in Canada were built in Alberta. Yet, despite the province's advantages for solar and wind energy, in 2023 a seven-month moratorium was imposed on renewable-energy projects. New rules were then announced that include a ban on new wind projects within 35-kilometre "buffer zones" around protected areas and other so-called "pristine viewscapes". In addition, an "agriculture first" approach is now mandated when evaluating projects on agricultural lands. The new rules have caused several dozen projects to be abandoned.

## Electricity

Electricity is currently generated by a mix of fossil fuels and green energy. The composition of sources and CO<sub>2</sub> emissions vary widely by country and often by region within a country. However, the composition does not convey accurately either the marginal resource and environmental costs of electricity generation or the consumer price that reflects full social marginal costs. One reason is that sources such as nuclear and hydro operate continuously to supply base load. Other sources such as natural gas are deployed to meet peak demands. Intermittent sources such as solar and wind are harnessed when available. The incremental cost of electricity depends on which source is on the margin to supply additional demand, and the sources vary in their emissions intensity.

A second reason why the mix of local energy sources is not indicative of marginal costs is that some electricity grids are interconnected across regions and countries. In Europe, nuclear dominates in France, hydro in Norway, solar in Spain, and wind in Denmark. Electricity consumed in one country may be generated in another. Connecting the diverse sources has the advantage of smoothing total grid capacity over time and reducing the need for storage and reserve capacity. Nevertheless, as the share of renewables grows, electricity imports and exports, prices, and emissions are likely to become more variable.

Electricity demand is forecast to increase in coming decades due to progressive electrification of transportation, heating & cooling, and industry, and rapid growth in artificial intelligence. This has raised concerns about the stability of electricity networks and whether capacity will be adequate in the long run.

### Renewable energy for transportation

Transportation is responsible for a large share of total GHG emissions. Emissions are caused not only by vehicle movements but also during construction of vehicles, roads, and other transportation infrastructure. Transportation is considered the most challenging economic sector to decarbonize. The potential is good for private passenger transport since electric vehicles are declining in cost and improving in range. The potential is also good for urban public transportation since buses, trains, and trams run on fixed routes and can be powered directly from the electricity grid without using batteries. Electric bicycles and scooters are also viable for short distances, and ride sourcing and car sharing can be provided using electric vehicles.

Powering other modes of transportation by electricity or other green energy sources is more daunting because of heavy loads and long distances. For heavy goods vehicles, four technologies are under consideration: alternative liquid fuels (methane, ammonia, synthetic diesel), battery electric trucks, hydrogen fuel-cell electric trucks, and electric-road systems. All have drawbacks such as added weight, safety, and high infrastructure costs.

For aviation, energy sources under consideration include biofuels, synthetic fuels, hydrogen fuel cells, and battery or hybrid-electric aircraft. Enabling long-range flights is a major challenge. For maritime shipping, candidates are low-emission hydrogen, ammonia, biofuels, and other synthetic fuels. All the alternatives face hurdles to adoption at scale. According to IPCC (2022, p. 32), the overall transportation sector is unlikely to achieve net-zero CO<sub>2</sub> emissions even by 2100.

### Social acceptability

The speed at which renewable energy replaces fossil fuels will depend not solely on the physical characteristics and costs of energy and energy-using equipment. Social acceptability matters as well. Fournis and Fortin (2016) identify several dimensions of acceptability. One is a distinction between social acceptability concerning process, and social acceptance of results. For example, a proposal to establish a wind farm may be turned down because the process that was followed did not give residents sufficient opportunity to express their concerns. The proposal would then fail the *ex-ante* test of social acceptability. Had it been promoted in an acceptable manner that led to implementation and successful operation, it would have gained social acceptance on the basis of the *ex-post* results.

Fournis and Fortin (2016) also distinguish between three types of acceptance that differ in the set of stakeholders. ‘Socio-political acceptance’ applies broadly to major social actors such as politicians and the general public. ‘Community acceptance’ refers more narrowly to specific projects and siting decisions, and to local stakeholders concerned by procedure, distributive justice, and trust. Finally, ‘market acceptance’ concerns whether innovations or projects succeed in the market place, which depends on consumers and the entrepreneurship of investors and businesses.

Various scholars have studied social acceptance towards renewable energy sources and other climate-related actions such as carbon capture and storage. Three studies will be mentioned here.

Moula et al. (2013) investigate Finnish attitudes towards renewable energy technologies. From the results of a multiple-choice questionnaire, they determine that personal attitudes and public

acceptance are influenced by several factors: socio-economic characteristics such as age and income, knowledge and direct experience of renewable energy, environmental, and political beliefs, and attachment to where people live. A strong sense of place attachment tends to intensify both support and opposition to energy initiatives. Procedural aspects of zoning, planning, siting, and licensing decisions also influence attitudes.

Fournis and Fortin (2016) investigate the social acceptability of wind energy projects. From a literature review, they identify several factors contributing toward negative attitudes: if planning follows a mechanical top-down pattern or ignores the local context, if the project is outside the respondent's territory, if information is deficient or suspect, and if opportunities to participate in decisions are lacking.

Stigka et al. (2014) conduct a literature review of contingent value studies of willingness to pay (WTP) for renewable energy sources. They determine that WTP increases with disposable income and education, is raised by negative experiences with conventional electricity supply problems, and also raised if jobs are created. By contrast, WTP falls with age and household size, is lower for respondents who are responsible for paying electricity bills, is lower in rural areas that have suffered environmental impacts of renewable energy supply projects in the past, and is discouraged by search costs for alternative energy supplies or suppliers.

As noted above, political beliefs can influence attitudes toward green energy. Davis et al. (2023) find strong evidence in the USA that ideology matters for adoption of electric and plug-in hybrid vehicles. They determine that sales of new vehicles between 2012 and 2022 were concentrated heavily in counties with the highest proportion of Democratic voters. Surprisingly, the pattern did not appear to decline over the ten-year study period. Davis et al. also find suggestive evidence that individual purchases were driven less by intrinsic motives (i.e., personal satisfaction at being a good global citizen) than extrinsic motives (i.e., virtue signaling to other people).

Attitudes toward CCS are broadly similar to attitudes towards renewable energy. Support is higher among people who have been adversely affected by climate change. Support is lower in communities that have been negatively affected by industrial activity or insufficiently informed about, or involved with, CCS project decisions. Attitudes are affected by knowledge about successes or failures of CCS projects elsewhere, as well as by degree of trust in project developers and governments. Environmental organizations often oppose CCS as an inadequate means of compensation by fossil fuel companies for their past actions (see the discussion of social responsibility above), and sometimes accuse them of greenwashing.

The fossil-fuel industry has understandably resisted measures to phase out carbon-based fuels, particularly if it results in substantial loss of market share and profit, stranded assets such as abandoned coal mines, and lost jobs. However, financial pressure from capital markets and government support for green energy (notably the 2022 US Inflation Reduction Act) have accelerated investments in green energy by major fossil-fuel companies as well as de novo green companies.

Attitudes towards fossil fuels, renewable energy, and energy policies are clearly influenced by who gains and who loses. Household gains and losses are determined by myriad personal characteristics including household income and size, type of employment, geographical location, exposure to pollution, and health status. Individual firms and whole industrial sectors can have much at stake as well. Inequalities in the incidence of gains and losses, both within and between countries, tend to create perceptions of unfairness, and impede or prevent agreement on what climate-related policies should be implemented. Given the complexity of

climate change, misperceptions in the gains and losses are common and can be exacerbated by biased and false information propagated by social media.

Some energy-related policies such as consumer subsidies are widely considered unfair. For example, according to a recent U.S. study, “tax credits for buying heat pumps, solar panels, electric vehicles, and other ‘clean energy’ technologies .... have gone predominantly to higher-income households .... The most extreme is the tax credit for electric vehicles, for which the top quintile has received more than 80% of all credits.”

### Concluding remarks

A transition is underway from fossil fuels to renewable energy sources. Progress varies across economic sectors, countries, and regions within countries. Due to the inherent advantages of fossil fuels, and huge investments in equipment and production processes designed to operate with fossil fuels, the transition will be protracted. Yet, it is essential if CO<sub>2</sub> emission reduction targets are to be met. At least in democracies, securing social acceptance for alternative energy sources and demand management policies is also essential. The distribution of benefits and costs matters, but acceptability also depends on procedural fairness, distributive justice, and trust.

Various renewable energy sources, methods of energy conservation, and other green initiatives have either been deployed or are under study. A number are likely to play significant roles in the evolution toward a carbon-neutral world. Digital technologies such as sensors and artificial intelligence can help to increase energy efficiency, manage electricity networks, and guide consumer decisions.

Economists have long argued that a carbon tax or tradable carbon permit system can serve as the primary tool for internalizing climate-change-related externalities and providing consumers and firms with sufficient incentives to make socially efficient decisions. However, carbon taxes and heavy-handed environmental regulations have met strong opposition in many countries. Moreover, carbon taxes (or equivalent) are designed to internalize negative externalities from carbon emissions. Acemoglu et al. (2023) argue that this is not enough to support an efficient transition toward a carbon-neutral world because investments in green technology create another, positive knowledge externality that calls for a subsidy. They further warn against using less-polluting fossil fuels such as natural gas as transitional measures “because they reduce incentives to invest in green innovations.”

In conclusion, it should be emphasized that climate change and policies to combat it are subject to many uncertainties that will persist for a long time. These include the supply of rare metals and other raw materials, geopolitics, environmental policies, and the evolution of public attitudes toward climate change and the environment.

## 7. How does manufacturing face the climate change crisis?

Industrial activity is, directly and indirectly, the main cause of the GHG emissions responsible for the rapid climate change we are facing. It does so directly through its manufacturing processes and indirectly through the use of some of its products. In this section, we analyze the capacity of companies to change in order to achieve zero greenhouse gas emissions.

We first retrace the prolonged history that has led to the current situation, and then list and quantify the social constraints that we will have to face, using the automotive industry as an example. These constraints may be internal to the industries concerned, but also external through the social repercussions on their host territories. However, some industrial teams and

scientists are not without expertise in the complex processes involved in solving large-scale problems.

### Evolution of companies and their products

Artisanal and industrial activities and the products they produce developed only gradually over much of the period since the Industrial Revolution. Disruptions only occurred after wars due to social upheaval and industrial reconstruction in the affected countries. However, since the end of World War II, companies have continuously adapted their manufacturing processes to remain economically and technically competitive. These evolutions often involved the introduction of targeted improvements aimed primarily at the well-being of their customers, shareholders, and employees, such as safer product usage, reduced harmful emissions during use, enhanced durability and ergonomics, and new technologies to increase efficiency, whether economic or for users and employees. Household appliances, transportation equipment (e.g., cars, public transit, airplanes), urban planning schemes and so on were thus designed through a delicate balance between optimizing economic performance and enhancing the well-being of the populations they served.

### The impact of companies and their products on climate change: a slow adjustment

Due to climate change, companies' activities and the products they manufacture have global as well as local effects. People are affected whether or not they use a firm's products or live near where they are produced. Limiting or even eliminating greenhouse gas emissions has become one of this century's greatest challenges for industries and product users.

Around the world, many economic sectors and industries emit greenhouse gases, including transport, agriculture, metallurgy, and chemicals. Added to these are industries that rely on raw materials whose extraction and/or refining also produce greenhouse gases. These include electronics, renewable and other non-emitting energy production systems, and even health-related products like medicines and medical analysis machines. There is a vast network of large- and small-scale production activities that interact with each other, creating numerous feedback loops. The more wind turbines that are built, the more renewable electricity is generated, but the greater the need for neodymium and steel produced by greenhouse-gas emitting processes. This situation is even more pronounced for electric or fuel cell vehicles used for passenger and freight transport.

Migration and urbanization patterns, demographic growth, and even social structures have all evolved around these industrial and artisanal activities, intensifying greenhouse gas emissions (IEA 2024). This is evident through increasing individual consumption of manufactured products, the rising consumption tied to population growth, and the popularity or necessity of these products across increasingly vast territories. In some cases, improving quality and durability—while seemingly virtuous—have also increased greenhouse gas emissions. For example, the simultaneous development of a dense road network and the sale of personal and commercial vehicles reduced transportation costs, created jobs, and improved access to sparsely populated regions. Higher production quality standards improved vehicle durability, nearly doubled vehicle lifespans, and allowed many people to purchase affordable second-hand vehicles. However, this also led to increased car mileage and, consequently, more transport-related greenhouse gas emissions (European Environment Agency 2022).

### Constraints and the search for solutions to the climate crisis

Addressing the climate crisis successfully will inevitably affect the well-being of much of the world's population. Disturbances to well-being will cover a very wide range of items that often are not directly linked to each other, as the following list shows.



One important disturbance is the stability of many jobs in directly or indirectly emitting industries (automotive, much of freight transport, steelmaking, chemical industries including medical, etc. Five important dimensions are: (1) The payment of pensions, which rely on investments in affected industries. (2) The distribution of activities across territories (factory locations, lack of non-emitting transport options in rural areas...). (3) The reassessment of raw materials used in product manufacturing and, consequently, existing economic and geopolitical balances. (4) Loss of government revenue, particularly from fossil fuel taxes. (5) Obsolescence of skills based on patent pools designed to protect economic benefits.

To illustrate this industrial and social revolution, the following paragraphs focus on transport. Climate change has not been the guiding principle of the automotive industry's development policy. To understand the situation in the face of climate change, the interesting question is: How have manufacturers developed their products over the years, and what could be the risks involved in switching to zero-emission vehicles?

Whether for individual, collective, or industrial use, the primary goal of transport equipment manufacturers is product reliability (Feigenbaum 2004). The owner of a truck, bus, or car is rightly very demanding about this. Reliability refers to a vehicle not breaking down before a certain mileage and its bodywork not corroding. Over time, mileage expectations have increased. In the 1980s, 100,000 km was the acceptable mileage for a car, whereas today, it's over 150,000 km. For light commercial vehicles, the acceptable mileage is about 50% higher. Manufacturers won't disclose their internal benchmarks, but they will use the warranty period and mileage as a selling point. This roadmap, which aims to improve the quality and durability of vehicles, has helped to reduce greenhouse gas emissions per kilometer from car manufacturing as measured per kilometer over a vehicle's lifetime.

Cost is the second most important factor for vehicle manufacturers (Deming 2013). The road vehicle market is highly competitive, unlike the oligopolistic markets for airplanes and trains. In France alone, for example, 51 makes and 161 models of car are available to customers. Media comparisons of technologies, equipment, technical reviews, and pricing are widespread. Manufacturers quickly lose sales if their product is more expensive than a competitor without an offsetting technological advantage. Their profitability, or more specifically their operating margin (Sherkenbach 1986), primarily depends on production costs and warranty costs, directly linked to product quality. Manufacturers aim for high production volumes to reduce costs. This goal was clearly not motivated by climate change concerns. However, competition between manufacturers may weaken their ability to make the transition to low greenhouse gas emission vehicles. This transition will require major investment, with no guarantee that the costs will eventually be recovered. A drop in sales volume, even if temporary, could lead to a reduction in employment at manufacturers and suppliers and have repercussions in other sectors due to the reduction in income and purchasing power of former employees.

The next question to assess is what the carmaker's strategy might be in the face of the switch to zero-emission vehicles?

Automotive manufacturers are not opposed to stricter safety or environmental standards. They've complied without issue with regulations requiring catalytic converters and particulate filters, as well as airbags, seatbelt pretensioners, ABS, and dual external mirrors. They've also promptly launched electric vehicles and hybrids. When lobbying governments, they usually advocate for purchase incentives to avoid losing operational margins and company value.

In such an uncertain environment, manufacturers and their suppliers will lobby for financial aid. They will also highlight the social risks that could arise. This does not prevent managers from trying to exploit changes in legislation to increase their operating margins, but it may be

possible to identify such behavior from annual financial statements. An increase in operating margin of more than 3 points in one year warrants scrutiny.

To be sure, automotive manufacturers do not lobby about everything such as building more parking spaces or roads, or even speed limits. At most, they fight to ensure that motor sport is not banned. It has been a long time since motor sport was used to validate technical innovations. Such lobbying is inconsistent with the desire to promote frugal behavior on the part of motorists, lorry drivers, and bus drivers.

The final question is how to involve manufacturers in the policy of switching to zero-emission cars, despite the difficulties mentioned above?

Whether a private or commercial car is attractively designed, comfortable, quiet and pleasant to drive, it can contribute to the well-being of its users. On the other hand, using or choosing a car without considering its environmental impact will be detrimental to the well-being of more and more people. Respect for the environment will rise to the same level as respect for the safety of others when driving. Both of these issues will be increasingly demanding. Those in charge of the automotive industry are aware of this, and it is up to legislators, with the help of technical experts and economists, to create a sustainable and credible roadmap that will ensure that the well-being function evolves in a continuous and shared manner, and not in a caricatured or brutal way. Because of the greenhouse gas emissions produced by transport, this objective has become global and cross-cutting for all countries' political management models.

#### [Social risks for the transition to a green industry: automotive industry example](#)

Here we quantify the social risks associated with the transition to an industry free of greenhouse gas emissions, again using the automotive industry as an example.

In France, for example, the emissions from all forms of transport totaled 126 Mt, with 120 Mt from road transport alone (SDES 2024). Reducing transport emissions can be approached in three ways: (1) Drastically reducing car and road transport use, leading to a significant disruption in current well-being. (2) Shifting from fossil fuel-powered cars to electric vehicles, requiring profound changes in the automotive industry. (3) A combination of both approaches.

A combination of the two approaches seems the most likely. Drastically reducing car use is feasible in the heart of major cities. But in the suburbs, it would be very expensive to build a comprehensive public transport network with connections to other modes of transport such as cycling. Changes would also be required in the locations of commercial and service centers in response to changes in mobility.

The situation is much more complex in rural areas. The car has sometimes enabled these areas to sustain a large enough population to maintain a network of schools, and to make the 10 to 20 km journey to commercial and service areas acceptable. Distributing activities back to villages and small towns in these areas will considerably reduce their economic productivity and impoverish residents. In addition, public transport services will continue to be hampered by the low volume of people to be transported. This could lead either to an increase in transport costs or to low transport frequency. It is also likely that journey times will increase because of the number of stops to be served and the likely changes to bus or train service. All of these changes will very probably adversely affect the well-being of these areas which are already suffering a loss of population to cities and their suburbs, and/or already being abandoned by political classes (Chamorel 2019; Bordenet 2024).

In addition to the car's role in people's well-being, another major challenge will be its impact on car-related industries and services. Whatever their political model, the most industrialized

countries have integrated the road transport industry (private and commercial) into their development plans. Manufacturers have made it profitable to sell popular cars. The solution was to set up production lines producing several hundred thousand of these cars a year. This led to the creation of vast factories, each built on several hundred hectares of land, that can be seen using Google maps. For example, one of the largest car factories in the world is Lada (Avtovaz) in Russia, built in the days of the USSR. This is an interesting case that goes far beyond the factory itself: its development has increased the population of the town of Togliatti to over 700,000, making it the largest town in Russia that is not a regional capital. The example of Togliatti can be seen in Europe, North America, Japan, China, and India. Reducing production will have an impact on jobs. Changing powertrain technology (i.e., engine and gearbox assembly) from fossil fuel to pure electrification may lead to a reduction in the number of parts to be manufactured, and consequently a loss of jobs. If job losses occur in areas where car production is concentrated, further losses will occur among parts suppliers, ancillary industries and even in all other activities due to a strong decrease in way of life. This may happen in France in the Sochaux-Montbéliard or Cleon regions, in Germany around Wolfsburg, in Romania around Pitesti, or even in Sweden around Göteborg. What's more, as the less well-off employees of these plants often live in rural areas where property is more affordable, the decline in well-being in rural areas will be amplified.

The extent to which this risk of a breakdown in well-being, as perceived by the population today, extends to an entire country will depend on the share of the car industry in the country's manufacturing industry. In the European Union in 2022, the automotive industry provided 13.4 million jobs, including 2.4 million in manufacturing alone (ACEA 2024). These jobs vary widely from country to country. While they accounted for 6.8% of manufacturing jobs (214,904) in France, the percentage rose to 10.9% (872,446) in Germany, and as much as 15.5% in Slovakia (75,721).

As a result, the social and industrial situation could be similar to that experienced by certain mining and steel regions between 1960 and 1990. The example of the Sambre and Meuse valleys in Wallonia (Belgium) shows how people's well-being collapsed there, and how it can take a generation to rebuild an economy similar to that of unaffected regions.

Another challenge for the car industry and its satellite services (garages, road infrastructure maintenance, etc.) is the amortization of investments which can amount to 10% of the retail price of a car. These investments involve the purchase of machinery and tooling, some of which are highly specialized, in order to ensure the planned production rates and the maintenance activities. The economic viability of firms concerns not only shareholders, but also employees and customers. In addition to manufacturing tools, there is the problem of reusing buildings. A tour of the Sambre and Meuse valleys shows that the buildings of closed factories are very rarely re-used (e.g., Cockerill-Sambre to the east of Liège). The buildings slowly fall into disrepair, leaving a visible and depressing scar. When we think of the electrification of vehicles, we first imagine being able to reuse part of these buildings to build batteries. Unfortunately, the heavy weight of the batteries requires concrete foundations much thicker than those of most existing buildings. This inevitably raises the question of whether to upgrade or abandon existing facilities.

Another consequence of the industrial transition towards net-zero is the change in materials required to make and use vehicles. Today's cars run on fossil fuels and require large amounts of steel and cast iron to make camshafts, crankshafts, gearbox pinions and shafts, and part of the engine blocks. As all or some of these materials are no longer needed in purely electric vehicles, demand for them will drop. Demand for other materials such as copper, cobalt, nickel, and neodymium will increase and may exceed current extraction and production capacities for

some time. Countries that use these materials to fuel their economies will need to develop a culture of recycling as close as possible to 100% to protect themselves from supply disruptions or sudden price rises. Countries producing raw materials that are in decline will have to organize the economic and/or social crises that may ensue, as the local interpretation of the well-being of their populations (employees, investors, holders of capital) may be all the more severely shaken if they have no present or viable diversification in the short term.

This global movement of companies, populations, and states towards a net-zero future affects all categories of population, all regions of the globe and all models of socio-political management of countries. The problem to be solved is therefore a global one. It is hard to imagine any single country sustaining a major effort to overhaul its industrial and economic system on its own, while at the same time putting pressure on the well-being of its population. An in-depth analysis of the structures and behavior of existing systems will probably be necessary to choose an appropriate path to follow and a timetable for its implementation.

#### Capacity to navigate the transition to a greenhouse gas-free industry

The automotive industry has faced systemic crises before (as defined by Donella Meadows 1972). In the 1980s it rectified quality problems when cars rusted and broke down before 100,000 km (Sherkenbach 1986; Deming 2013). Addressing the climate crisis will require a similarly thoughtful, determined, and collective approach, focusing on education, problem analysis, customer respect, and persistent improvement, offering inspiration for solving the climate crisis with care and rigor (Feigenbaum 2004). Many actions can, and should, be taken to address the climate crisis.

## 8. Territorial Approaches to Meet International and National Commitments

### Context: From Global to Local

While commitments to address climate change are established at international and national levels with specific targets based on each country's responsibilities, effective mitigation and adaptation strategies must be implemented at regional and local levels. The OECD (2023) proposed a framework of territorial climate indicators to guide how cities and regions should align with national and global climate targets. Local solutions must engage all stakeholders—including policymakers, developers, businesses, and citizens—in efforts to reduce GHG emissions and mitigate climate change impacts (Galarraga et al., 2017). Additionally, the relationships and resource flows between urban and surrounding rural areas should be integrated to foster an approach grounded in the "territory of life." As defined by Barles (2009), this concept of territory of life refers to an area where populations share common services and participate in activities that meet their daily needs.

Achieving global carbon neutrality as swiftly as possible requires rapid transformations everywhere to reduce fossil fuel consumption, which accounts for roughly 80% of GHG emissions, primarily emitted in urban areas (over 60% of total emissions, UN-Habitat, 2020). However, the path to achieving neutrality varies based on historical emission responsibilities. Developed countries are restructuring their economic and social frameworks to achieve energy efficiency and sufficiency. Developing countries, with an urgent need for economic growth, should pursue innovative pathways that balance sustainable advancement with the well-being of their populations. Robust international cooperation is essential to support these efforts (IPCC 2022).

At the city level, the Covenant of Mayors, initiated in 2008 with European Commission support, and the Compact of Mayors, launched at the 2014 UN Climate Summit, exemplify such

international cooperation. In 2017, these initiatives merged into the Global Covenant of Mayors for Climate & Energy (GCoM) to support urban climate action. GCoM signatories aim to reduce their GHG emissions by 44% by 2030 and 66% by 2050 (GCoM website). Kona et al. (2021) studied 167 cities worldwide and suggested that more ambitious and easily tracked climate targets are necessary for cities to align with global climate change mitigation goals

The importance of mitigation and adaptation across sectors like transportation, residential, industrial, energy, and agriculture is widely recognized as essential for addressing climate change (IPCC 2018). There is a growing recognition of the need for a globally coherent approach to defining climate measures, considering their interconnections with other critical dimensions: environmental (biodiversity, health), social (poverty, inequality, social cohesion, democracy), and economic (investment appeal).

It is worth mentioning that excluding energy, climate, and air quality considerations from territorial planning can lead to inconsistencies. (a) Increased use of local biomass for urban heating, instead of fossil fuels, could reduce GHG emissions but might also expose the population to air pollution, harming health (Zauli-Sajani et al. 2024). (b) Expanded bioenergy usage necessitates long-term biomass resource management and a comprehensive evaluation of environmental and social impacts, including biodiversity and carbon sequestration. Integrative approaches remain inconsistently developed (Pilogallo *et al.* 2024), and the coexistence of regional and national climate policies raises coordination challenges (Landauer *et al.* 2019).

Opportunities to maximize co-benefits from integrated solutions still need to be identified (Zusman et al. 2021). For instance, investing in intercity and intracity public transportation can substantially reduce GHG emissions, particularly in high-density areas, while reducing inequality, improving social cohesion, air quality, and public health (lowering related social and health costs). The roles of public and private transportation, along with the transition from combustion engines to electric vehicles, require further examination to optimize local and regional energy systems, reduce air pollution, and prevent the worsening of social inequalities. Demonstrating the effectiveness of large-scale solar and wind energy adoption, combined with energy efficiency, heat recovery (e.g., co- and tri-generation), and dynamic energy storage (e.g., infrastructure for electric vehicles and buildings), is essential to achieve energy savings and reduce local and global pollution. Comprehensive decision-making tools are needed to guide local authorities in formulating robust investment plans.

In France, the 2007 *Grenelle de l'Environnement* led to the *Grenelle I* (2009) and *Grenelle II* (2010) laws, establishing cohesive national responses to successive European Directives on environmental responsibility (2004/35/CE), water (2000/60/CE), waste (2008/98/CE), renewable energy (2009/28/CE), building energy performance (2010/31/UE), industrial emissions (2010/75/UE), bird conservation (2009/147/CE), and more.<sup>4</sup> Evaluating this collaborative governance remains complex, as it depends on sector-specific interests, which may sometimes conflict (e.g., Halpern and Pollard, 2017).

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<sup>4</sup> The Regional Climate, Air, and Energy Plans (SRCAE) were created and incorporated into the Regional Planning, Sustainable Development, and Territorial Equality Schemes (SRADDET) in 2019, following the 2015 NOTRE Act. Additionally, the 2015 French Law on Energy Transition for Green Growth (Law No. 2015-992) transformed local Climate-Energy Plans (PCET), initially introduced in 2004, into Climate-Air-Energy Plans (PCAET). These reforms encouraged new governance structures that promote dialogue and cooperation across decision-making levels and sectors among various stakeholders (e.g., public, private, and environmental organizations).

## Challenges

Despite continuous efforts to create climate mitigation and adaptation strategies that also address local issues (e.g., air quality, urban climate, biodiversity, and poverty), various challenges persist, including technical, organizational, and political obstacles. The following subsections detail some of these challenges.

**INTEGRATED APPROACH VS. SPECIALIZED EXPERTISE:** Local authorities need to reorganize to foster collaboration among traditionally separate internal services (e.g., land use, biodiversity, buildings, mobility, social cohesion). This reorganization highlights the need for shared climate data and information across departments (e.g., Swart et al., 2021). Open data platforms are emerging to provide local authorities and non-expert stakeholders with reliable data on energy, GHG emissions, air pollution, and climate impacts. These platforms facilitate cross-learning, stakeholder collaboration, and help to define coherent local policies and track territorial progress (OECD 2023).

However, accelerating sustainability transitions poses challenges in internal expertise and training for public authorities, particularly under constant or reduced budgets. External consultants often handle studies and evaluations, raising critical questions about the selection process for private sector experts and their roles (Keele 2019).

**STRENGTHENING CITIZEN ENGAGEMENT IN LOCAL POLICIES:** Increasingly, the role of citizens in urban planning and decision-making on climate and energy issues is being debated (Perlaviciute and Squintani 2020). The Aarhus Convention, established under the United Nations, serves as the primary legal framework guaranteeing citizens' rights to information and participation in environmental decisions. France's Citizens' Convention on Climate has sparked debate on the effectiveness of such participatory processes: most of its proposals were not incorporated into the "Climate and Resilience" French law (Kervasdoué 2020).

At the municipal level, public consultations provide community feedback on local urban projects, ensuring resident voices are heard. Yet, public discourse on more global, long-term ecological plans and specific solutions for reducing fossil fuel use, GHG emissions, and protecting communities from future climate disasters is limited, despite the need for policies with far-reaching environmental and societal impacts. Engaging citizens in meaningful discussions to explain global constraints (e.g., biodiversity and climate protection, limited resources) and find collectively acceptable solutions remains a significant challenge. For instance, the Eurométropole of Strasbourg's Development Council (CoDev), created in 2015, serves as a metropolitan dialogue and citizen engagement platform. It was used to update Strasbourg's climate plan; challenges have included sustained citizen engagement, representativeness, funding, recognition of citizen contributions, and communication of outcomes to the broader public.

**RESEARCHERS' ROLE IN SUPPORTING LOCAL POLICIES:** In response to the emerging contradictions, debates, and tensions in various sectors, researchers must adapt their approaches to continue providing objective, practical analyses. Multidisciplinary and interdisciplinary research is essential to develop integrated decision-making tools and methodologies that effectively support sustainable territorial planning. Participatory action-research projects that engage policymakers, planners, businesses, and citizens in a territorially grounded approach are essential for understanding local dynamics and supporting multicriteria decision-making. These projects help propose adaptive, sustainable solutions that maximize societal benefits while minimizing costs and inequalities. This is illustrated well by a recent initiative that involves a wide range of stakeholders in research-action on climate change (e.g., Long-Term Socio-Ecological Research platforms, LTSER; Dick et al. 2018).

## Conclusion

In regional and urban territories, well-being is a central concern, as the issues are tangible: How can we protect populations from climate change? How can GHG emissions be reduced without causing new conflicts? What compromises are needed to tackle the challenges of sustainable development at minimal cost without burdening future generations with debt? International policies and movements are progressively encouraging local authorities to propose integrated solutions that, in turn, require new forms of cooperation among local actors. Their effectiveness must be evaluated to accelerate societal transformation.

## 9. Concluding comments

We are all searching for solutions to the climate crisis, which largely revolves around energy supply and access to raw materials. According to the World Energy Outlook 2023, the global energy mix is composed of 31% oil, 27% coal, 23% natural gas, 6% hydropower, 4% nuclear, and 9% renewable energy (including solar, wind, geothermal, and bioenergy). By 2050, in the "Net Zero Emissions by 2050" scenario (NZE), the share of fossil fuels is projected to decrease to just over 20%, highlighting a significant shift away from coal, oil, and natural gas towards renewables. While this is an ambitious goal, it raises numerous challenges to which we currently have no definitive solutions. The transition is both necessary, due to the depletion of energy resources and raw materials, and urgent in light of the ongoing climate challenges.

Such a transition would demand profound changes in our society, where energy remains central to daily life. Today, energy consumption is split among industry (36%), transport (29%), buildings (30%), and other sectors (5%), such as agriculture and non-energy uses like feedstocks in petrochemicals. Solutions must address a multitude of constraints, including technical, temporal, economic, social, and environmental dimensions, making the problem almost overwhelming. This calls for a collective, multidimensional, top-down and bottom-up approaches to reflection and action.

Taking the example of electric vehicles (EVs), achieving substantial implementation by 2050 would require not just replacing internal combustion engine (ICE) vehicles, but ensuring EVs align with changes in lifestyle (e.g., adoption of smaller cars), urban planning suited to public transport, and the availability of clean and abundant energy. Moreover, rare materials must be efficiently recycled to avoid creating a future environmental burden, and affordability must be maintained. Additionally, the industrial sector must manage the transition without triggering mass layoffs, which would devastate communities dependent on traditional automotive jobs. This example illustrates that the challenge goes beyond implementing policies like a carbon tax (such as the EUA contract for December 2024 set at €71.81/t).

Consider a second example. Climate change has particularly severe consequences in densely urbanized areas due to the concentration of human activities and vulnerable infrastructure. According to United Nations projections, the global population is expected to reach approximately 10.4 billion by 2100. Rapid urbanization, particularly in large cities across Asia and Africa, will exacerbate the impact of extreme weather events such as floods, heatwaves, and rising sea levels. Furthermore, the growing strain on infrastructure such as roads, buildings, and energy networks increase maintenance and adaptation costs. In this context, the combined effects of demographic and economic growth, along with urban sprawl, amplify environmental risks while simultaneously heightening demand for infrastructure and housing. For now, this seems like trying to square the circle, and degrowth is not a viable solution at the moment: we need to be more inventive.

The key message of this article is that a range of solutions must be explored and rigorously studied within the academic community before they can come to fruition. To date, these solutions often rely on frameworks disconnected from real-world complexities. Acknowledging the challenges of interdisciplinary dialogue within our group, we emphasize that if academia aims to contribute effectively to the climate change discourse, it must first learn to communicate internally to better engage with external stakeholders. This collective understanding is crucial for fostering more robust and actionable strategies in the global fight against climate change.

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