: vivideconomics

The Inevitable Policy Response: When, What and How

Policy pathways to below 2°C and estimating the financial impacts

Paper prepared for the Principles for Responsible Investment

Climate Thought Leadership

September 2018

PRI Principles for Responsible Investment

An investor initiative in partnership with UNEP Finance Initiative and UN Global Compact

Supported by:

ClimateWorks FOUNDATION

Contents

List of tables

List of figures

1 Introduction

Investors today do not fully recognize the likelihood and impact of an 'Inevitable Policy Response' to climate change

Investors today do not fully recognize the likelihood and impact of an 'inevitable policy responses (IPR)' to climate change. Instead, most investors as with companies appear anchored around concrete policy commitments as captured in the IEAs New Policies Scenario (NPS), leading to inadequate 'pricing in' of climate policy risks as a reflection of the incomplete action-to-date. However, the IPR will involve a step change in both the level and coverage of climate policy action, with a period of subsequent market re-pricing exposing investors to significant volatility and potential losses. Therefore, a better understanding of how the low carbon transition will impact financial markets is essential.

This paper lays out *when* the IPR could occur, *what* policy pathways it could take, and *how* these policy pathways affect the macro-economy and risk-returns of financial assets. An increase in ambition is considered inevitable due to a combination of political, economic, social and ecological pressures as explained in *why*. The analysis in this paper provides the basis for understanding what this new policy reality will consist of and how it will impact institutional investment portfolios, as taken up in *Strategic Asset Allocation, Managing Stranded Assets* and *Investor Actions* papers. Those papers then explain how these factors will impact institutional investors as the climate transition is factored into asset pricing. Together, these papers form the basis for further work through an IPR intended research programme in 2019.

An increase in ambition is considered inevitable due to a combination of political, economic, social and ecological pressures

Section 2 of this paper lays out those factors driving *when* the IPR is likely to occur, arguing that a global response to climate change is increasingly likely to be announced by 2025 and enacted in the following years. According to the Paris Agreement, a stock-take of emissions will be conducted in 2023 and new international and domestic emission targets will be set in 2025 – this will make even more starkly apparent the gap between existing emissions levels and the pathways consistent with limiting the damages from global warming. Combined with more apparent (physical) impacts of climate change, continued technological advances, and increasing pressure to create greater future certainty, the period to 2025 will likely trigger a forceful IPR.

Section 3 illustrates *what* an IPR might entail, arguing that a policy response to get the world from the current trajectory to well below 2°C would be dramatic, but could take multiple forms. Policy pathways that have the ambition to limit global warming to 2°C or below with a 66% probability require dramatic decreases in emissions and changes across the global economy. Meeting the goal of the Paris Agreement to limit global warming to well below 2°C will require the world to reach net zero emissions by 2060-2070.[1] A

[1] Rogelj et al., "Paris Agreement Climate Proposals Need a Boost to Keep Warming Well below 2°C."

quicker timeline may be needed if tipping points are considered.[2] Recent reports indicate that negative emission technologies plus peaking of emissions within the next few years are needed to limit global warming to 1.5°C.[3] This equates to halving emissions every decade and doubling the share of zero-carbon energy every 5 to 7 years.[4] Scenarios illustrating such a shift indicate that by 2050, 25-75% of cars would be electric, most of the remainder would be run on biofuels and the transport system would be significantly more efficient.[5] The electricity sector would be either 95-100% carbon free and the carbon intensity of the industrial sector will have decreased by 80% compared to 2017.[6] Greenhouse gas removal technologies would need to be quickly scaled up to reach 0.5 $GtCO_2$/year in 2030, 2.5 by 2040, and 5 in 2050.[7]

This IPR requires dramatic decreases in emissions and changes across the global economy

The IPR could take multiple forms, with this paper focusing on proven and feasible mitigation policies but also examining policies that facilitate and encourage 'negative emissions'. It examines what policy packages might be consistent with keeping the world to well below 2°C after a period where investment stays consistent with the Paris NDC pledges, which imply a world with 2.6 to 3.4°C warming as illustrated by the IEA NPS. Providing an exact and fully-quantified prediction of what policies will be implemented is impossible. Nevertheless, determining asset exposure and carbon risk levels requires a detailed and credible understanding of what the policy response to keep the world within 2°C might involve. This paper outlines the broad policy package that will be needed to keep warming to well below 2°C in an orderly fashion (e.g. as assumed in the reference scenarios of the IEA) and how this could change if a policy response is delayed to the specific timeframe of 2025-30. The analysis here remains illustrative, forming the basis for an intended research programme to be carried out in 2019.

It is now urgent for investors to consider the implications of the Inevitable Policy Response

Section 4 sets out a modelling approach to quantify *how* an IPR might change both the expected returns and risks to major asset classes and regions following an IPR, as summarized in Figure 1. This combines estimation of the macro-economic impacts using economic system models, as well as a bottom-up estimation of company and sector impacts. The geographic focus is twofold: first, to understand the inevitable policy response, a global view disaggregated by regions and/or countries is needed. Only the global policy response indicates whether emissions are in line with limiting global warming to well below 2°C. Second, to understand the impact on investors, the impacts on a country level are crucial. Here, the focus is on the countries that represent the largest share of economic activity, with the US, China, Europe and Japan representing that vast majority. The overview in section 4 provides the roadmap for further work in the next phase.

[2] Cai, Lenton, and Lontzek, "Risk of Multiple Interacting Tipping Points Should Encourage Rapid CO2 Emission Reduction."

[3] Rogelj et al., "Scenarios towards Limiting Global Mean Temperature Increase below 1.5 °c."

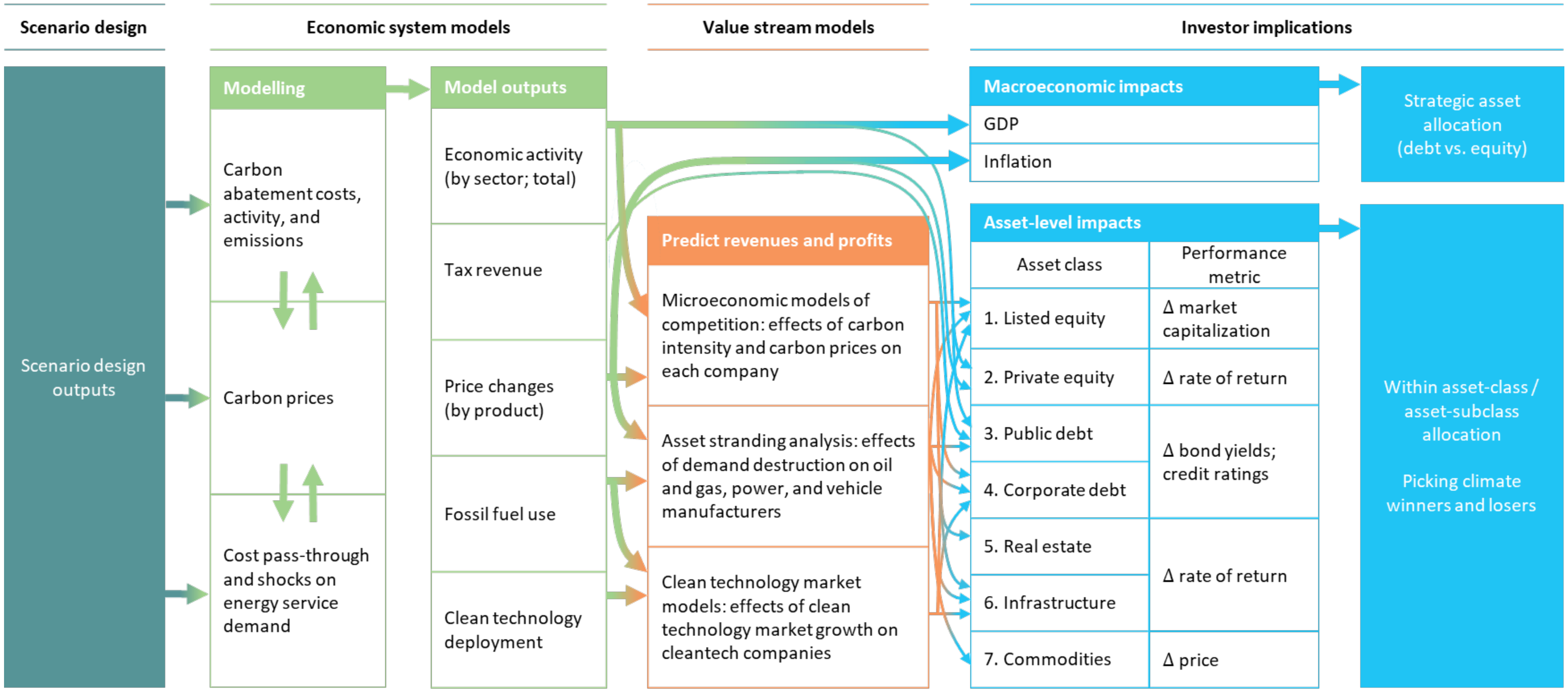
[4] Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, "A Roadmap for Rapid Decarbonization."

[5] OECD/IEA and IRENA, "Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System"; Rogelj et al., "Energy System Transformations for Limiting End-of-Century Warming to below 1.5 °C."

[6] OECD/IEA and IRENA, "Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System."

7 Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, "A Roadmap for Rapid Decarbonization."

Figure 1. **The work translates the Inevitable Policy Response into implications for investors**



Source: *Vivid Economics*

2 Timing of the inevitable policy response

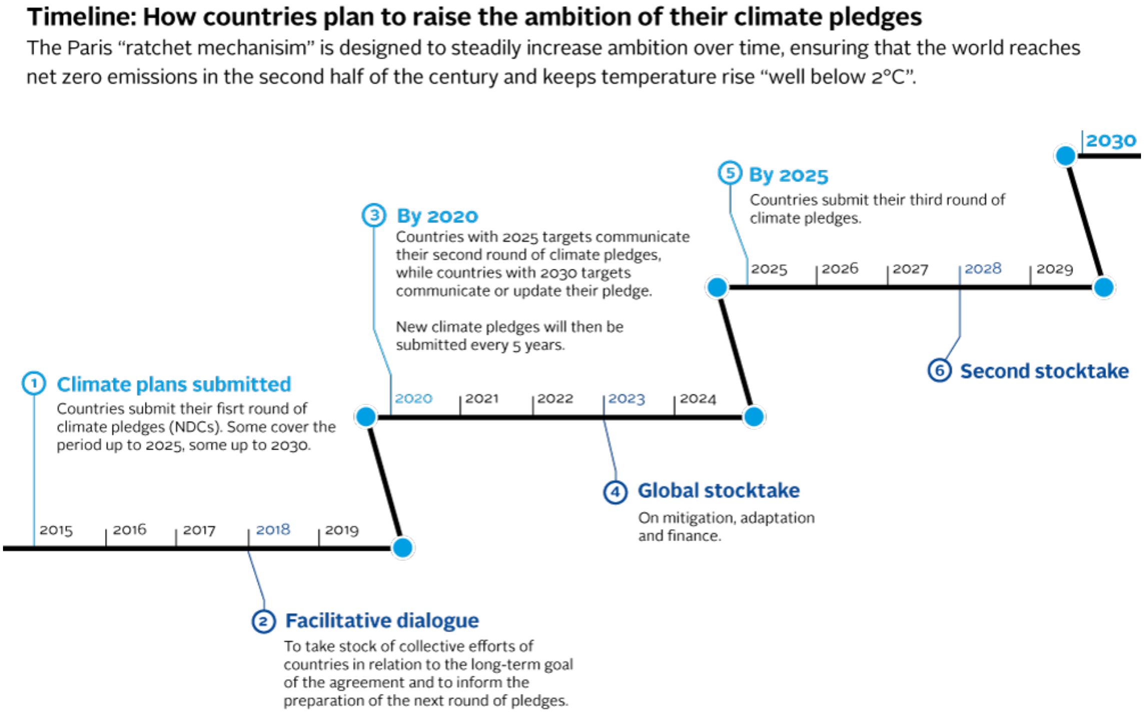
The Paris Agreement combined with a series of external drivers is increasingly likely to trigger an 'inevitable policy response' by 2025.

The Paris Agreement sets the policy framework and process that could trigger a global response to limit global warming to well below 2°C. The Agreement is a pledge and review agreement. It entered into force on the 4th of November 2016, and 178 countries had ratified it by the end of June 2018. Under the agreement, countries must submit climate pledges, or 'nationally determined contributions' (NDCs) every five years starting in 2020. 189 countries have already submitted pledges for either 2025 or 2030. In 2020, countries with 2025 targets need to submit new pledges with a target year of 2030, while countries with 2030 targets need to communicate or update their existing pledges. Countries would have to make each round of NDCs more ambitious than the last (Article 4.3), in 'a progression beyond the Party's current NDC and reflecting its highest possible ambition'. Regional and country level policy initiatives also feed into this process – for instance, US state level policies have advanced significantly without a federal impetus.

These rounds of pledging will be accompanied by five-year collective reviews called 'global stocktakes' starting in 2023. These stocktakes review the collective action of countries so far in reducing emissions and providing finance and how existing pledges track against agreed global goals. These stocktakes are intended to inform the political process and amplify public pressure. A summary of this pledge and review structure is provided in Figure 2.[8]

[8] The Paris Agreement is legal treaty that is only loosely legally binding. It is established as a legal treaty by Articles 20 and 21 which state that it is "subject to ratification, acceptance or approval". This means it is binding under international law, but it has obligations to bind with. Countries are primarily required to submit a new nationally-determined pledge and clarifying information every five years. They are not bound to meet these targets. Importantly there is no enforcement mechanism to ensure that obligations are followed, and only a facilitative mechanism for compliance. The agreement instead relies on political and financial pressure generated through its pledge and review structure.

Figure 2. **The global stocktake and third round of climate pledges could catalyse the inevitable policy response**



Source: *Carbon Brief*

Current pledges are not on track to meet the stated goals of the Paris Agreement

Current pledges are not on track to meet the 'well below 2 degrees Celsius' goal of the Paris agreement. Under Article 2 of the Paris Agreement countries have agreed 'to limit global average warming to 'well below 2 degrees Celsius above pre-industrial levels' and to pursue efforts to limit the increase to 1.5 degrees Celsius. Article 4.1 specifies this temperature target as part of a long-term goal of net zero emissions in the second half of the century. That is, a state where anthropogenic emissions are matched by removals from sinks. Various studies assessing current pledges estimate that they would result in between 2.6°C and 3.4°C of warming by the end of the century, well above the agreed global target.

Nevertheless, the combination of the Paris Agreement's ratcheting-up process with a number of underlying drivers could credibly trigger the Inevitable Policy Response in a timeframe up to 2025. As argued in the WHY paper, there are a number of plausible triggers that might shift the current policy trajectory to the well below 2°C trajectory targeted by the Paris Agreement:

- **Mounting desire for policy certainty among businesses** driven in part by a rapidly growing awareness of the large and increasing scale of asset stranding that would be caused by sudden and erratic policy shifts; and in part by the growing opportunities available in 'green' sectors
- **Rapidly decreasing cost of technologies** required for the low carbon transition whereby a number of sectors are reaching a turning point where low carbon is now lower cost, hence increasing their acceptance by consumers, tax payers, and ultimately policy makers
- **Growing certainty about the extent and costs of long-term physical climate damages** especially as the pace of global warming becomes clearer and estimates of damages more precise, sending a wake-up call to the private owners and public stewards of vulnerable assets and populations

- **Near-term manifestations of climate-related impacts** such as significant droughts, heatwaves and wildfires which spark a sudden increase in public concern and intensified political pressure

Although it is impossible to predict with certainty when an IPR will take place, these triggers are aligning actors in a common direction, intensifying the impetus for action, and reaching potential tipping points such that investors should treat an IPR by 2025 as a significant possibility.

More so than in the past, these triggers are set to sway the breadth of actors – citizens, consumers, businesses and government – whose alignment makes an IPR more likely. A broad set of actors are potentially impacted by climate change and the response to mitigate it. Sufficient alignment across these actors will be necessary to achieve a policy response that credibly establishes a commitment to well below 2°C. The triggers laid out above are sharpening points of common concern and interest more than ever before and resolving some of the long-standing (perceived) conflicts that caused of policy inertia. The combination of improvements in low-carbon technologies and the desire to preserve asset values (e.g. oil and gas) from stranding has now created a stronger business interest in a near-term policy response. At the same time, the lower cost of low-carbon technologies and the increasing concern with the costs of climate-related impacts has created a strong citizen and consumer interest in seeing a near-term policy response. Finally, these same drivers have created a broader base of governments that feel action is in their interest, resolving in particular the perceived conflict between growth and green in developing countries.

These underlying drivers are intensifying and becoming more certain with each passing year, driving the case that a strong policy response is urgent in the run-up to the global stocktakes and ratcheting-up of pledges. In addition to the alignment of interests, the timing of an IPR is driven by the perceptions (across these interests) of the costs-benefits of acting now versus later. In the past, the case for a strong policy response was tempered by critical uncertainties about the scale and timing of climate change, and about the aggregate economic costs and distributional impacts of climate action. As long as the costs of climate damage were perceived as potentially quite low (and far in the future), and the costs of mitigation action were perceived as potentially quite high (but decreasing over time), there was space to argue for delay. However, the triggers laid out in *why* push clearly in the other direction – they are increasing the certainty about the costs and timing of climate damages, and they are raising the cost of delayed mitigation efforts versus timely mitigation efforts.

Moreover, the above triggers involve specific thresholds that could drive tipping points in the policy response. Not only are the underlying drivers pushing steadily in a direction that increases the case for action, they are also moving toward specific thresholds that could tip the scales rapidly. For example, once low-carbon technology costs cross a certain price point, they move rapidly from being a positive-cost policy choice to a negative-cost policy choice. Similarly, climate change impacts are subject to thresholds and feedback loops that can induce sudden shifts, with damages or expected damages increasing many-fold quite suddenly. Although it is difficult to say when we will reach enough tipping points to induce an IPR, the *why* paper shows a number of important cases where we appear to be at or quite close to such tipping points.

Even though some nations or sub-national regions could remain unmoved by these triggers, it is increasingly credible that a coalition of leaders could drive an IPR even without full international coordination. Full support from all nations has been a perennially elusive goal, and this is unlikely to change in the next 5-10 years – there remain a set of governments for whom it is not in their interest to take action over their relevant political timeframe. A leadership of countries and regions could drive an IPR more widely through their inordinate weight in a globally interconnected political and economic system. The necessary critical mass of leaders remains uncertain, but there are various combinations of major players that could credibly hit 50% of the world economy.

Finally, it is important to keep in mind that the investor impact from an IPR could occur through a credible 'announcement effect' that takes place well before the implementation of a full set of policies. A policy response will take time to both coordinate and implement, and within the context of the Paris Agreements, it could take the form of steadily stringent steps. Nevertheless, an 'announcement effect' of the implementation of stricter climate could immediately change how investors value assets. This could occur through the announcement of future policy commitments, or even by establishing a clearer pattern of increasingly stringent policies (i.e. without announcing longer term commitments per se). Hence a policy response announced in 2025 need only set a clearer signal to the market, with fuller IPR implementation occurring in steps to the second round of pledges under the Paris Agreement in 2030.

There are certainly events that could slow or even reverse progress toward an IPR, but the increasing likelihood of such a response makes it imperative for investors to consider. This section has laid out some of the reasons an IPR by 2025 is a serious possibility. More in-depth assessment of the potential triggers of an IPR will help investors better arrive at their own viewpoint. Given the potential scale of *what* such an IPR would entail, it behoves investors to incorporate an IPR into their expectations of likely futures.

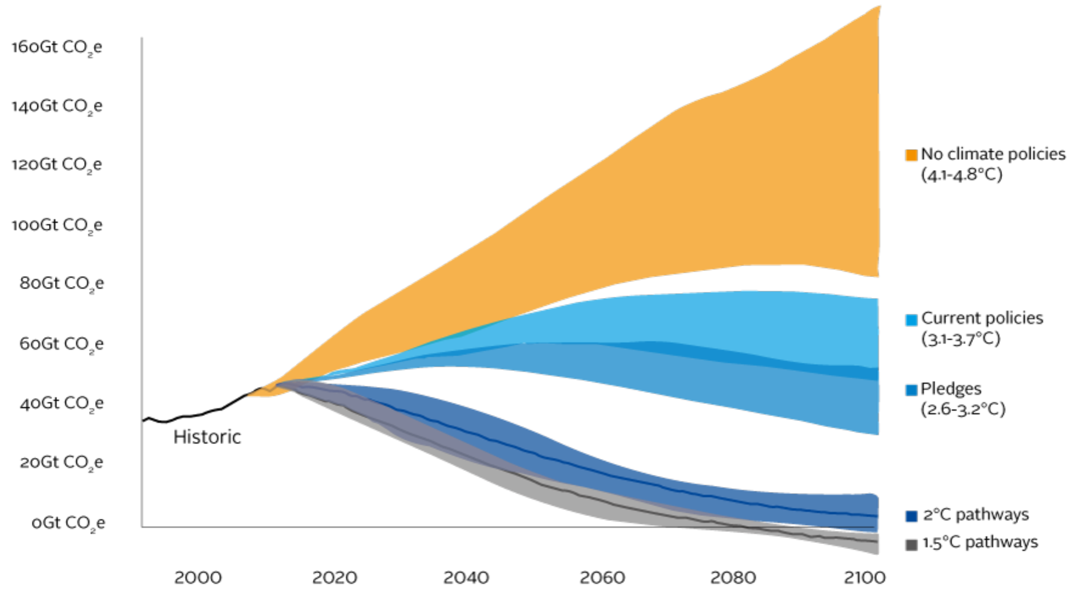
3 Policy pathways to below 2°C

Combinations of policies are needed to limit global warming to well below 2°C. These are best understood through scenario analysis due to a lack of historical evidence and considerable uncertainty in future climate policy and technology developments.

Most scenarios which keep warming to 1.5-2°C warming are characterized by emissions peaking before 2020.[9] If countries are to meet the goals of the Paris Agreement in a relatively orderly fashion (e.g. avoiding massive asset stranding) they will need to begin ratcheting-up their pledges before 2025. That is, they will need to voluntarily increase their climate ambition before they are prompted by the first round of pledge and review under the Paris Agreement.

Despite this, it appears unlikely that countries will significantly increase their ambition and/or avoid carbon lock-in over the next few years prior to the timeframe established by Paris. Governments continue to commission electricity from coal or other fossil fuel sources that are exceeding emission budgets for the power sector consistent with a 2°C trajectory. In response, many companies continue to use the IEA's NPS – a scenario far above a trajectory for 2°C – for their planning towards 2030 (see e.g. the recent responses of oil and gas companies to the Task Force for Climate-related Financial Disclosures). The full extent of the gap between the near-term action and the required action of the Paris targets will become apparent from the first stocktake in 2023, and from that point the required political action will need to be even more dramatic, as shown in Figure 3.

Figure 3. **A forceful inevitable policy response will be needed to reduce emissions towards a 2°C trajectory**



Source: Our World in Data

[9] IPCC Assessment Report 5

Delayed action means foregoing cheaper emissions reductions today for more costly action tomorrow. The impacts of GHG emissions on global warming are cumulative and long-lasting, and a significant proportion of high-emissions assets are long-term capital intensive. At the same time, to the extent it increases uncertainty, delayed policy action will reduce low-carbon innovation, and further increase the expected costs of the climate transition. Delay thus results in overall greater economic costs, financial risks and equity losses, with greater asset stranding and an increased transfer of capital to more costly emissions reduction options, including negative emissions technologies. In short, delaying the inevitable policy response causes financial destruction, rather than Schumpeter's creative destruction.

Forward-looking scenario analysis is essential to make robust decisions today

---

Scenario analysis is of vital importance, due to a lack of historical evidence and considerable uncertainty in future climate policy and technology developments. The finance industry's traditional approach of estimating historical relationships between key variables as a basis for forecasting future returns is not well suited to assessing climate transition exposure. There is no historical experience of carbon policies at the level necessary to avoid climate disaster. Forward-looking models based on scenario analysis allow estimating impacts on key economic variables, such as GDP, oil prices, sectorial composition, and provide investors with an understanding of the underlying mechanisms driving long-term changes in asset valuation.

While *a* policy response is inevitable, the severity, timing and global coordination of the IPR remain sources of uncertainty which investors will have to assess. Realistic IPR scenarios will be conservative on when policy action ramps up due to existing inertia and slow rates of change. However, policy timing is still a key source of investor risk due to short-lived assets and high discount rates in important sectors such as energy equities. The *relative costs* of different emissions abatement technologies is another material source of uncertainty; the cost of renewables, energy efficiency measures, and carbon capture and storage will affect disruptive technology deployment and underlying asset returns. Explicit views of future climate policy and technology scenarios are developed to address and quantify the effects of these uncertainties. Scenarios will be developed using the latest carbon budgets (severity thresholds) identified by the IPCC in its upcoming Special Report on Global Warming of 1.5°C.

The process of building climate scenarios of investor relevance will involve a greater level of detail than policymaker scenarios reported in the literature, such as the IEA's ETP scenarios. Policymaker scenarios focus almost entirely on the general macro-economic impacts of IPR with a focus on overall climate policy ambition (e.g. well below 2°C versus 3°D). These omit other policy and technology uncertainties that affect investor returns and may therefore understate volatility in returns. Moreover, policymaker scenarios focus almost entirely on rational policy choices undertaken in an orderly fashion and with considerable foresight, rather than more realistic policy choices made under uncertainty and with significant political influence.

3.1 Building blocks of policy pathways

Policies to reduce emissions differ in their impact on financial markets

Policies that are part of the IPR can be classified into categories. For this overview, it is useful to consider four categories in particular:

1. Carbon pricing;
2. Targeted demand-side policies;
3. Targeted supply-side policies; and
4. Policies to support carbon sequestration (including negative emissions).

Both across and within these categories, different policies can have different impacts on macro-economic variables such as inflation and GDP growth, as well as on sectoral and company returns. For example, carbon pricing is economically quite efficient (e.g. with the lowest impact on GDP), but can also bring to bear quite strong and direct 'market discipline', destroying existing and potential equity value. On the other hand, more supportive supply and demand-side policies and policies to encourage carbon sequestration can recycle equity value through governments, potentially compensating companies whose value is destroyed and/or channelling value into other emerging industries. These impacts will be explored with the methods laid out in Section 4.

The aim is to broadly sketch out what policy levers are available to generate a forceful IPR. Future work is needed to explore the scenarios and combination of polices and their impacts. The following details the nature of the policies that might be part of the IPR.

3.1.1 Carbon Pricing

By far the most predominant and important demand side policies are those that seek to restrict demand for emissions intensive inputs (especially fossil fuels) – carbon pricing and regulation and standards. Both policies seek to ensure that the cost of using or consuming emission intensive inputs is high enough to encourage emissions reductions at a socially optimal level. The decision about the sectors in which different policies are applied usually depends on which policy is most efficient and feasible given the specific nature of that sector. Ideally, these policies would be well-calibrated to ensure the most efficient and effective pathway of emissions reductions. In practice, calibrating policies effectively across different sectors has proven quite difficult, and there is often significant divergence in the cost of emissions reductions across sectors.

Carbon pricing will be indispensable for limiting global warming to well below 2°C

Carbon pricing is the most efficient way of reducing emissions across an economy,[10] and it is already a policy that is widely deployed and under consideration across major countries. Carbon pricing takes a range of forms, including emissions trading schemes (ETS), carbon taxes, or a hybrid between the two with

[10] Rogelj et al., "Energy System Transformations for Limiting End-of-Century Warming to below 1.5 °C."

price ceilings and floors in an ETS.[11] Regardless of the form, there is emerging agreement around the level of pricing needed.

The carbon price to reach well below 2°C needs to be high and it needs to increase steeply over time. On average, studies estimate a carbon price of \$39-62/tCO_2e during the 2020s, \$54-190/tCO_2e during the 2030s and \$139-423/tCO_2e by 2050. Ranges are high as they span differing scenarios, as shown in table 2. These studies do not consider scenarios of delayed emissions reduction.

Table 1. **Carbon prices to keep the world of 2°C or well below will be far higher than most prices today and need to escalate quickly**

Study		**Carbon price (\$/tCO_2e)**		
	Model Scenario	*2020(s)*	*2030(s)*	*2050*
High-level Commission on Carbon prices[12]	To meet Paris 2°C target	40–80	50-100	N/A
IEA, 2017	Sustainable Development Scenario	43-63	125-140	N/A
Rockstrom et al, 2017[13]	To meet Paris 2°C target	>50	N/A	400
CDP, 2018[14]	To meet Paris 2°C target	24-39	30-60	30-100
Carbon Market Watch, 2017[15]	To meet Paris 2°C target	40-80	50-100	N/A
Guivarch and Rogelj, 2017[16]	To meet Paris 2°C target	N/A	15-360	45-1000
Rogelj et al., 2018[17]	To meet a 1.5°C target	N/A	50-165	N/A

These prices are dramatically higher than today. There are currently 51 carbon pricing initiatives around the world with prices ranging from <\$1/tCO_2e through to \$139/tCO_2e.[18] However, only 13 of the current carbon pricing schemes are above \$10/tCO_2e. Prices of around \$40/tCO_2e by 2020 are required to limit warming to 2°C, and even stricter policy will be needed to meet a 1.5°C target. The gap to this target represents the inevitability of stringent policy action.

[11] Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, "A Roadmap for Rapid Decarbonization."

[12] Stiglitz et al., "Report of the High-Level Commission on Carbon Prices."

[13] Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, "A Roadmap for Rapid Decarbonization."

[14] CDP, "Carbon Pricing Corridors."

[15] Carbon Market Watch, "Pricing Carbon to Achieve the Paris Goals."

[16] Guivarch and Rogelj, "Carbon Price Variations in 2°C Scenarios Explored."

[17] Rogelj et al., "Scenarios towards Limiting Global Mean Temperature Increase below 1.5 °c."

[18] Stiglitz et al., "Report of the High-Level Commission on Carbon Prices."

A lowest-cost policy response will require international coordination, and ideally the linkage of carbon pricing instruments

An international carbon market could halve the costs of delivering emissions reduction by the middle of the century and lower the costs of meeting current nationally determined contributions (NDCs) by a third.[19] This reduction in prices make higher ambition both more probable and feasible. Yet, international coordination across the globe is difficult. An international policy response is more likely to take the form of a 'climate club': a plurilateral group of countries with some common policies and likely a shared carbon market.[20]

Any coalition acting as a 'carbon club' will likely employ punitive measures to entice other countries to join the policy response. The most likely measure by a critical mass of acting countries is a common border tax adjustment.[21] This is particularly the case if the necessarily high-carbon prices are employed, which will heighten competitiveness concerns. Such taxes are compatible with World Trade Organization rules given the correct design.[22] While their effectiveness in changing the actions of other states and protecting against leakage is still contested [23], they will likely be a political necessity to appease emissions-intensive trade-exposed industries.

Sticks will likely be accompanied by the carrot of climate finance and international assistance. Many existing pledges are conditional on international assistance and finance. These could lift collective mitigation efforts by 2-53%.[24] This situation will likely continue into future pledging rounds. Given this, and the historical importance of equity to international negotiations, any future carbon club will likely offer substantial international assistance to developing countries to entice them to join the policy response. These flows of resource could have significant impact on, for example, fossil fuel dependent countries and their ability to service debts.

These are simply the general contours of how an inevitable policy response could be coordinated internationally. The specific details will depend on the countries involved –particularly the leadership countries taking action for the 2025 pledges–, the policies adopted and broader geopolitical considerations. However, it can be said with confidence that a policy response can only be effective and lowest cost if it involves the coordination of international efforts and prices, and that a climate club response would likely entail sticks (border-tax adjustments) and carrots (climate finance).

[19] McGlade and Ekins, "The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2°C."

[20] Nordhaus, "Climate Clubs: Overcoming Free-Riding in International Climate Policy."

[21] Green, "The Logic of Fossil Fuel Bans."

[22] Pauwelyn, "Carbon Leakage Measures and Border Tax Adjustments Under WTO Law."

[23] van Asselt and Brewer, "Addressing Competitiveness and Leakage Concerns in Climate Policy: An Analysis of Border Adjustment Measures in the US and the EU."

[24] UNFCCC, "Aggregate Effect of the Intended Nationally Determined Contributions: An Update."

3.1.2 Targeted Demand Side Policies

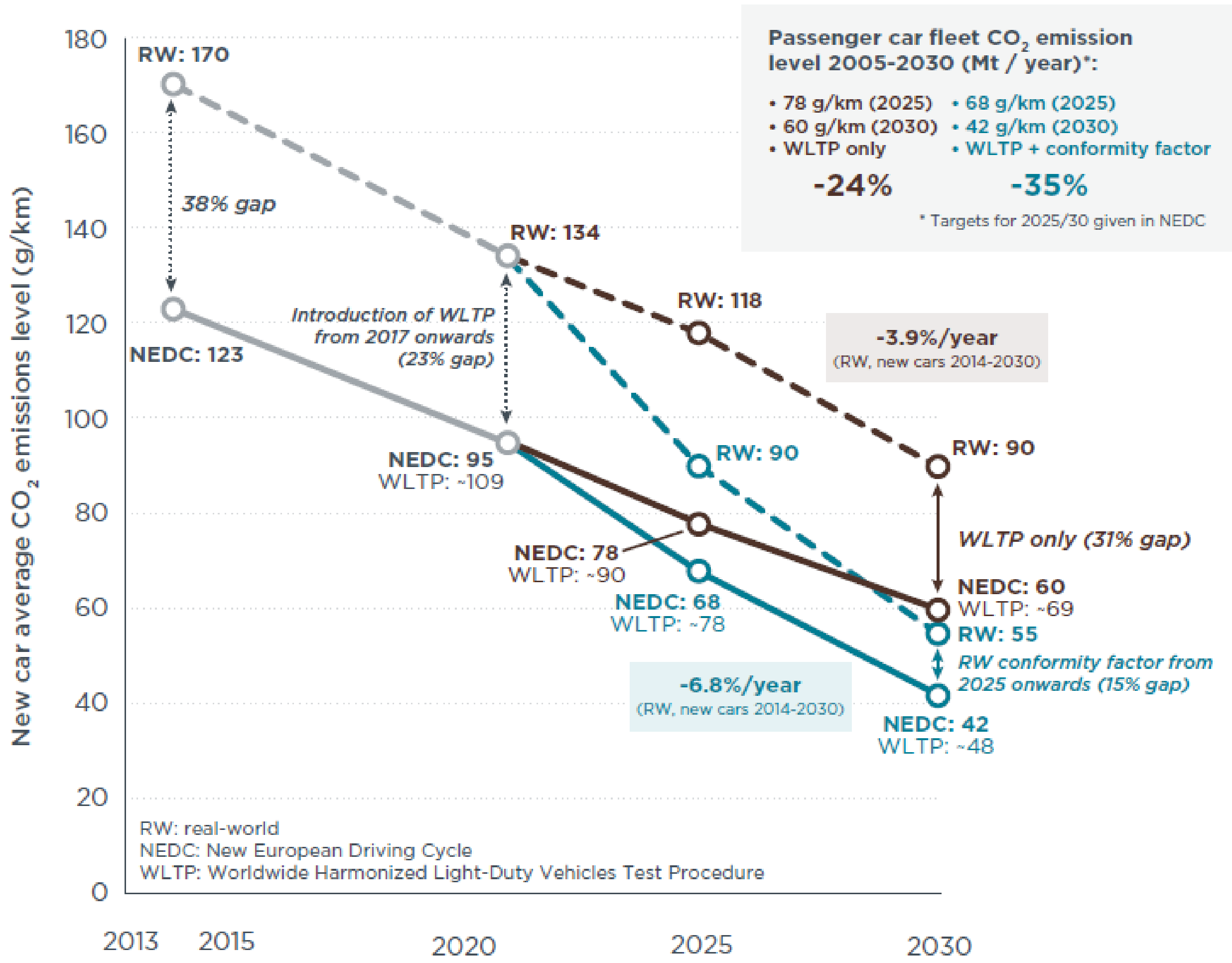
Widespread regulations and standards will need to be implemented to complement carbon pricing initiatives

Regulations and standards are the most prevalent demand side policies and are instrumental in encouraging energy efficient behaviour and a switch towards low-carbon transport (through vehicle emissions and efficiency standards), **buildings** (building codes and mandated retrofitting), **industry** (through updated equipment standards and retrofitting programme) **and consumer appliances** (through appliance standards). These command and control mechanisms have a strong track-record in environmental policy and are expected to continue to drive energy efficiency improvements, reductions in the emissions of industrial processes, and the decarbonization of the transport sector.[25]

For example, vehicle fuel emission standards play a key role in reducing global emissions. Stricter efficiency standards can encourage both more efficient ICE vehicles, as well as a switch to zero-emissions vehicles such as EVs or hydrogen vehicles. For passenger vehicles the most dominant pathway appears to be electrification, although there remains uncertainty about the role of hydrogen or biofuels. For heavy and light vehicles, there remains significant debate about the relative role of natural gas, biofuels, electrification or other zero-carbon options such as hydrogen. Fuel emission standards can be structured to drive this broad transition in an efficient manner, especially if well-aligned with carbon pricing policies. Figure 4 lays out a scenario for tightening standards toward meeting a 2°C world in an orderly fashion. In addition, several countries have begun to move forward with bans on the sale of *new* fossil-fuel based passenger vehicles as of a specific date (e.g. 2040), which implies convergence to a stringent zero emissions standard.

[25] Stiglitz et al., "Report of the High-Level Commission on Carbon Prices."

Figure 4. **Vehicle fuel emission standards would have to continue to tighten to be consistent with a well-below 2°C world**



Source: *International Council on Clean Transportation*

3.1.3 Supply Side Policies

Supply side policies aim to reduce the supply of fossil fuels and increase the provision of renewable energy. These policies help to meet two interrelated goals. First, by reducing the supply and changing the price of fossil fuels (the major source of anthropomorphic emissions) they help to reduce overall emissions. That is, they are a tool for mitigation. Second, these policies can help to directly minimize stranded assets by deterring fossil fuel resource exploration and infrastructure development. This latter goal is becoming increasingly important as carbon lock-in could lead to significant stranded assets before 2020, let alone 2025 (Pfeiffer et al, 2016). One study by the Potsdam Institute found that for scenarios to stay within 2°C '*huge quantities of installed coal capacity will need to be prematurely retired between 2030 and 2050. Such a vast global write-off of capital would be unprecedented in scale*.'[26]

Policies targeting fossil fuel supply are suitable for a more specific set of sectors than demand side policies, but where relevant, they offer a suite of economic and political benefits. Economic advantages include a low administration cost, avoidance of infrastructure 'lock-in', high abatement certainty and some

[26] Johnson et al., "Stranded on a Low Carbon Planet - Implications for the Phase out of Coal Power Plants."

reduction of the 'green paradox' (a rebound effect whereby fossil fuel use increases when their price is decreased by mitigation policies).[27] Different supply side policies offer differing benefits and costs, but all of these will likely be needed to limit warming to between 1.5°C and 1.75°C.

There would need to be an immediate phase-out of fossil fuel subsidies in countries undertaking the policy response.

If fossil fuels have not already been phased out at the start of the policy response in 2030 they would need to be ended without hesitation. Rockstrom et al suggest that fossil fuel subsidies already need to be eliminated by 2020, not 2025 as agreed by the G20.[28]

This pricing could be significant to reduce the exploration and development of all new fossil fuel resources. Existing fossil fuel reserves already exceed the 2°C budget.[29] Globally, 80% of coal reserves, half of gas reserves and a third of oil reserves need to be left unused to keep within the 2°C carbon budget.[30] This could be furthered to partial prohibitive pricing or outright bans. Numerous examples of this already exist: France has amended its mining code to ban the extraction of all fossil fuels within its borders by 2040. While the UK plans to phase out coal-fired power generation by 2025.

The supply of fossil fuels could be directly priced upstream at the point of extraction (well-head taxes). The easiest version of this is simply applying a tax upstream. The benefit in comparison to demand-side pricing is that there are fewer points of taxation which are fixed in-place. Thus, it is less administratively costly, and easier to monitor and verify. The upstream price would likely reflect the carbon price ranges summarized under demand policies.

3.1.4 Sequestration Supportive Policies

Carbon Capture and Storage may become essential – but not soon enough to avoid a broad-based IPR with impacts across all carbon-intensive sectors

While there is considerable scepticism, most low-carbon scenarios assume that CCS would need to increase significantly past 2025, encouraged by either pricing policies (carbon pricing or subsidies) or by direct regulation. CCS has the potential to serve two purposes in a transition to a well below 2°C trajectory. On the one hand, it can reduce emissions from fossil fuel generation (e.g. for power or industrial uses). On the other hand, it can create negative emissions in combination when used together with biomass power.

Nevertheless, the total global emission reductions CCS could achieve, as shown in Figure 5, and the focus on power and industry show the necessity for further policies responses in other sectors. Current technology cost and deployment estimates suggest that there will not be sufficient CCS deployed between

[27] Stiglitz et al., "Report of the High-Level Commission on Carbon Prices."

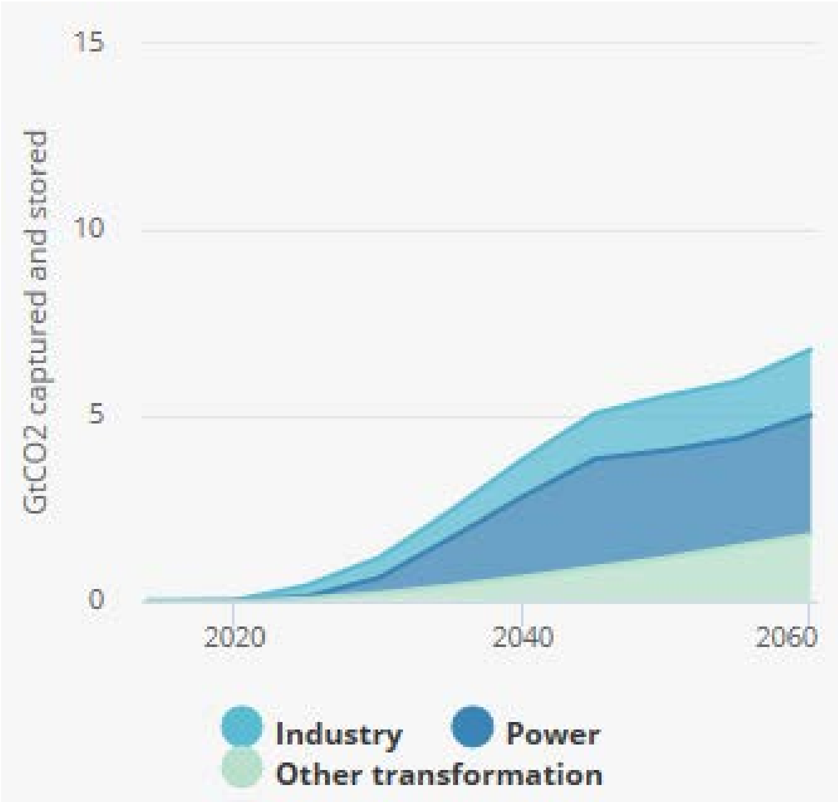
[28] Carbon Market Watch, "Pricing Carbon to Achieve the Paris Goals."

[29] Guivarch and Rogelj, "Carbon Price Variations in 2°C Scenarios Explored."

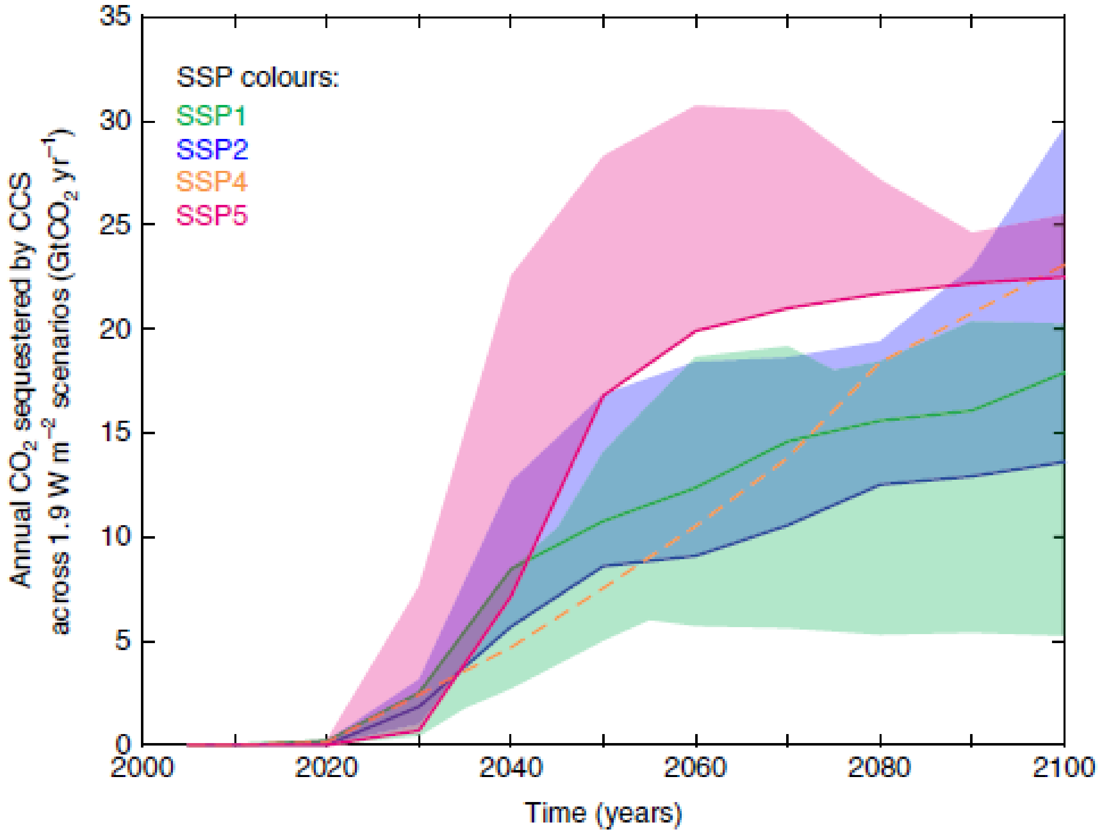
[30] Green and Denniss, "Cutting with Both Arms of the Scissors: The Economic and Political Case for Restrictive Supply-Side Climate Policies."

2025 and 2030 to reduce the need for a broad-based IPR with impacts across all carbon-intensive sectors. Further, CCS may turn out to be very regionally focused in key geographies that would have the ability to make this a government lead programme. China is the obvious case where the huge coal fleet either needs to be retired or retrofitted with CCS quickly.[31]

Figure 5. **CCS is unlikely be deployed at scale by 2025 or 2030 to avoid a broader policy response**



[31] Energy Transition Advisors, "Thermal Coal in Asia – Stopping the Juggernaut."



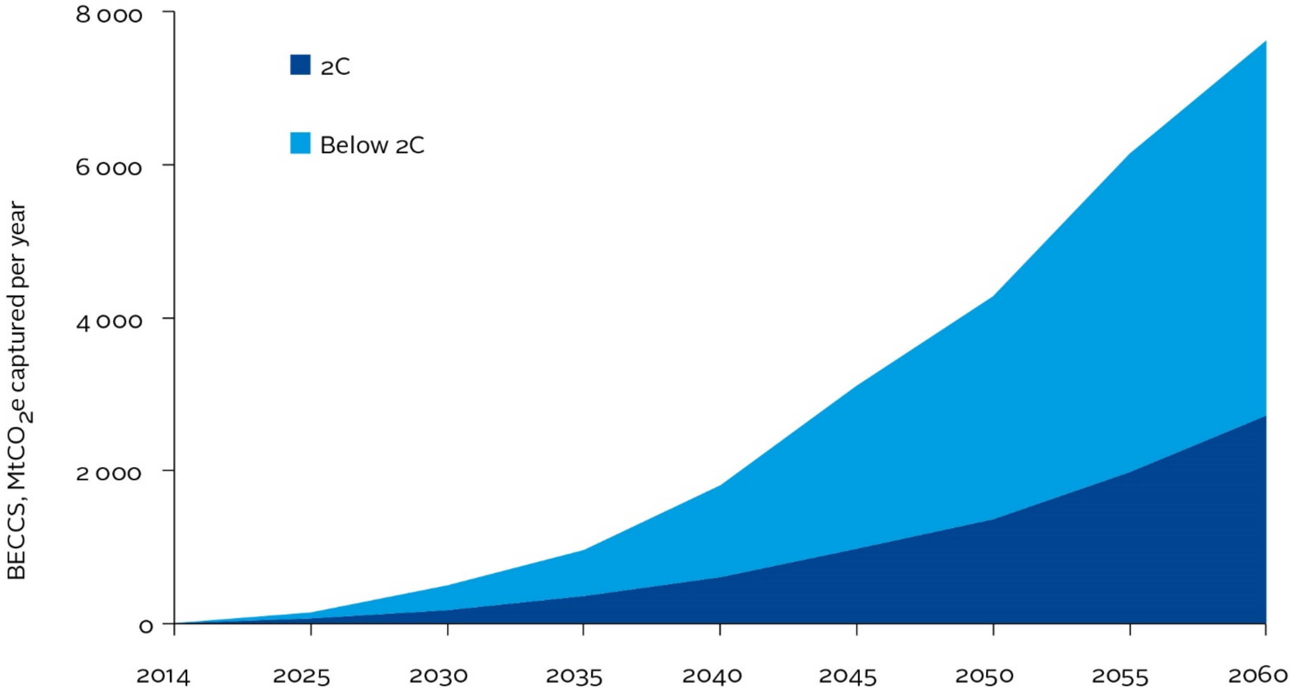
Source: Top: IEA. Bottom: Rogelj et al.

In most 2°C scenarios negative emissions offset less than 50% of cumulative fossil fuel emissions between 2010-2100.

For 1.5°C, this is 60-85%

101 of 116 IPCC scenarios rely on negative emissions by the end of the century to limit GHG concentration levels to 430–480 ppm CO_2 (scenarios with warming levels of 0.9–2.3°C). Given this, it is pertinent to consider these as part of the policy pathways to below 2°C and they scale up significantly more as shown in Figure 6.

Figure 6. **Negative emissions technologies must be adopted much more widely for a well-below 2C scenario**



Source: Vivid Economics. Data based on IEA Energy Technology Perspectives 2017.

Negative emissions are possible through both technological solutions (NET) and through Nature Based Solutions (NBS). They are technologies and practices that can drawdown and store or use greenhouse gases (GHGs) from the atmosphere. Negative emissions are risky and none of the available technologies are currently capable of commercial deployment at a wide-scale. Most have significant drawbacks, such as intensive use of land, or negative ecological impacts.[32] Table 2 provides an overview of the main negative emissions technologies that are either currently available or under development. NBS can ease the transition cost towards a well below 2°C target, with estimates stating that NBS could contribute more than a third of mitigation needed by 2030 for a 2°C target.[33] However, to date, NBS are complex and further research is needed to understand their potential impact on global emission reductions.

[32] Kemp, "US-Proofing the Paris Climate Agreement."

[33] Griscom et al., "Natural Climate Solutions."

Table 2. **Negative emissions centres on three key technologies with differing potential costs and benefits**

Approach	Description	Price Estimates	Abatement Potential	Potential Costs
Bioenergy with Carbon Capture and Storage (BECCs)	BECCs is the creation of energy from the combustion of biomass whose resulting emissions are captured and stored. A plantation forest or crop sequesters carbon from the atmosphere. This is then captured when the biomass is burned for energy, and then either permanently stored or used. The outcome is a negative emissions energy supply.	\$60-250/tCO_2[34]	3.5-20 GtCO_2/year, with 10 as a central estimate[27]	Land-use and efficiency cost of CCS.
Direct Air Capture (DACs)	DACs involves the actives sequestration of greenhouse gases from the air, usually through a chemical membrane. This is then either compressed and stored underground or transformed into a different material to be used.	\$20-600/tCO_2, with considerable uncertainty[35]	3.6-12 GtCO_2/year	Speculative with no at-scale or commercially deployable precedents.
Iron Fertilization	Iron fertilization is the spreading of iron filings over the ocean to encourage phytoplankton blooms. The phytoplankton take up carbon dioxide at the ocean surface and then sink to the bottom of the ocean when they die. This effectively takes carbon from the atmosphere and sequesters it to the ocean floor.	There are few price projections, but it is likely to be a low price with one source putting it around \$10/tCO_2[36]	1 GtCO_2-/year	Could cause ocean 'dead-zones'. Due to these fears, there is a moratorium on iron fertilization under the Convention on Biological Diversity. We have thus excluded it from our pathways.

Source: Vivid Economics; IEAGHG

NETs and CCS require financial support: by pricing carbon or by subsidizing such technologies or mandating their use

Subsidization and research and development funding could be used to develop promising approaches which are technologically immature. An obvious candidate is DACs, which may have few downsides but has no projects done at a sufficient scale, or that are commercially deployable. There are some existing examples**.** For instance, the US Government has already subsidized a small number of DACs project. University programmes in Canada have also performed trials with iron fertilization using public money.

Carbon pricing would provide a price incentive for CCS and, later, negative emissions. Most carbon pricing schemes pay the same price for a ton of carbon sequestered as a ton of carbon prevented from emission. In

[34] IPCC Assessment Report 5 (2014)

[35] Trull et al., "Position Analysis: Ocean Fertilisation: Science and Policy Issues."

[36] Trull et al.

which case, a carbon price could provide a useful revenue stream for negative emissions technologies. Importantly, carbon pricing would encourage scaling: a larger facility which draws down more tons of GHGs would receive a greater pay-out.

A differentiated carbon price (higher for sequestrating than for emitting) could be used to provide a greater price signal for negative emissions. Separate prices for mitigation and sequestration could be established. Sequestration would likely be assigned a higher price to reflect the comparatively higher price of necessary negative emissions activities.

Regulations could establish standard practices which require the use of negative emissions. For example, existing biomass plants could be required to be retrofitted with CCS or CCU (carbon capture and use) technologies, or else suffer a financial or legal penalty.

The work will investigate which combination of policy options to encourage sequestration is needed for the IPR, and how this policy mix impacts financial markets.

3.2 Creating policy pathways

Creating policy pathways identifies important sources of uncertainty and establishes likely levels of variation

The identification of the set of climate action levers is the first step in policy pathway design as stated in the SAA section. As described above, these levers are required to cover not only the severity and implementation of IPR, but also other key uncertainties such as technology cost. The TCFD scenario modelling recommendations should be followed as far as possible: investors should identify and explore key sources of financial sensitivity when performing climate scenario analysis. While the exact sources of uncertainty will vary on an asset-by-asset basis, a core set can be identified and explored even for investors holding highly diversified portfolios. These sensitivities have important implications for investors, for instance, diversifying clean technology portfolios can reduce risks around transition technology cost shocks.

The second step is to use expert judgement to inform likely levels of each climate action lever and develop consolidated scenarios. Expert judgement from climate scientists, policymakers and engineers is essential as an input to climate scenarios:

— **Climate scientists** inform the **carbon budgets** that are required to meet the IPR, depending on the level of stringency

— **Policymakers** inform expectations around the **likely timing, severity and coordination of climate action** – this is an essential step in calibrating what realistic pathways look like

— **Engineers** estimate **abatement technology costs** today, and potential **learning rates** or scale effects as deployment increases

These findings are consolidated into a set of scenarios which reflect the likely range of key climate policy and technology levers. Figure 7 sets out the framework for building climate scenarios.

Figure 7. **Scenario building identifies important sources of uncertainty and establishes likely levels of variation**

Source: *Vivid Economics*

The intended research programme will look at the most efficient ways to implement believable and impactful demand and supply side policies, including international cooperation scenarios. It will examine more precisely the likely stringency of these policies (e.g. the level of carbon prices) and it will assess how delay, or incomplete implementation, affects the likely forms of those policies.

3.3 Scenarios for the Inevitable Policy Response

A forceful policy response to limit global warming to 1.75°C or 1.5°C with 66% and 50% probability respectively

The response to reach either 1.75°C or 1.5°C with 66% and 50% probability respectively (and a range will be explored) will rely on some fundamental, necessary policies. Carbon pricing will be the bedrock of any cost-effective response. The carbon price will need to be high (54-190 $/t$CO_2$e in 2030) and it would need to increase quickly over time. Standards and regulations to encourage energy efficiency would need to be rolled-out, including a stipulation for all new buildings to be zero or negative carbon after 2030. This may be accompanied by the widespread enforced premature retirement of fossil fuel infrastructure or measures to drastically curtail their use and capacity.

The creation of all scenarios will account for the full range of uncertainty in likely future technology and policy implementation pathways. The intended research programme will define climate action scenarios in terms of emissions and temperature trajectories, technology costs, and policy pathways and their timing, using integrated assessment models (IAMs), technology transition models, and political economy models. This will include sensitivities such as deployment of CCS and use of NETS to create scenarios with and without these technologies.

The intended research programme will draw upon IPR scenarios in comparison to a 'committed policy' scenario such as IEA NPS and an 'orderly 2°C transition' scenario. These are used as comparators: 'committed policy' shows how financial markets would develop without further climate action. An 'orderly 2°C or below-2°C transition' shows how financial markets adjust to further climate policy. The Inevitable

Policy Response then leads to impacts on risk adjusted returns in comparison with these scenarios. The scenarios will then encompass:

- **Committed Policy** as evidenced in IEA New Policies Scenario (NPS). This a 'business as usual' base line to start from and to which the impacts of the more ambitious scenarios will be compared
- **Orderly 2C Transition** scenarios such as IEA ETP 2DS. These can be tested at 50-66% probability levels.
- **The 'delayed' 2025 for 2030 implementation IPR** based on 2°C and well below 2°C targets where NPS runs through most of that time frame

Policy assumptions in IEA scenarios consistent with orderly 2°C transition

- CCS: expanded deployment of CCS, from a total of 0.42 $GtCO_2$ in 2025, to 1.16 $GtCO_2$ in 2030
- Carbon pricing: staggered introduction of CO_2 prices in all advanced economies, with prices beginning at \$63/tCO_2 in 2025, and increase to \$140/ tCO_2 by 2040
- Fossil-fuel subsidies: phased out by 2025 in net-importers and by 2035 in net-exporters
- Transport: on-road PLDV stock emissions intensity limited to 55 gCO_2/km in advanced economies and 75 gCO_2/km elsewhere by 2040
- Efficiency and emissions standards: prevent the refurbishment of old inefficient plants
- Industry: enhanced minimum energy performance standards by 2025; incentives for the introduction of variable speed drives in variable load systems; mandatory energy management systems or audits.

Delay means a more sudden rise in the stringency of demand-side policies, and more stringent overall level by the 2030s and beyond

Delay will be costly. For example, carbon prices will have to rise significantly faster, and reach significantly higher levels by the 2030s and stricter mandates including forced retirement may be needed.[37]

- A policy response to bring the world on-track for below 2°C would mean an amplified spread of carbon pricing to cover at least all major emitters, as well as a significant increase of prices. This would require average carbon prices to increase at least four to six-fold in 2025 when the policy response is announced, or by 500-1900% in 2030 when the policy response is implemented. Depending on the country, and the degree of international collaboration, delay might also have significant impacts on the likely form of carbon pricing (e.g. a carbon tax vs. ETS vs. hybrid) and its efficiency, with important implications for economic impact and the value of financial assets.
- Similarly, regulations and standards would become more stringent over a shorter period of time and would need to apply to a broader set of sectors all at the same time. For sectors like transport, industry, buildings and appliances, it is possible that such an IPR scenario could involve levels of scrapping and refurbishment (i.e. ahead of the assets' usual lifecycle) that have yet to be considered, with consequent impacts on economic output and financial asset values.

[37] Green and Denniss, "Cutting with Both Arms of the Scissors: The Economic and Political Case for Restrictive Supply-Side Climate Policies."

Keeping to a well-below 2°C budget would require a radical shift in existing climate and energy policies

Based on the preceding analysis, this would include:

- Escalating carbon prices starting at 54-190 \$/tCO_2e
- Strong performance standards in power and transport in particular;
- New building codes for all new buildings to be carbon neutral or negative;
- Policies to phase-out and prematurely retire the existing stock of fossil-fuel infrastructure that is incompatible with the carbon budget;
- Significant state-sponsored research and development into low-emissions aviation technology, low-carbon high-grade process heat technologies such as plasma arc welding, and high-density batteries for the electrification of heavy vehicles;
- Subsidization of electric vehicle charging stations, along with tax and congestion charge exemptions for electric vehicles;
- Implementation of feed-in tariffs in many countries for solar PV, offshore and onshore-wind and solar thermal;
- A widespread roll-out of energy efficiency and consumer appliance standards, in particular for electric motors;
- Behavioural change policies to encourage dietary change away from animal products and energy efficient lifestyles; and
- Energy intensity targets for iron and steel, and cement.

However, the sweeping changes required for the well-below 2°C would involve instant reform of all energy sectors and the wider economy and are therefore unlikely to materialize. Therefore, IPR is the expected course of policy action.

The work will draw together what policy pathways are part of the IPR to estimate their impacts in the following section. These policy packages are region- and/or country-specific to understand how, in particular, fossil-fuel dependent countries are affected.

4 Estimating the financial impacts of the IPR

Forward-looking measures represent the best approach for estimating the strategic asset allocation (SAA) implications of IPR feeding into portfolio construction.

The decoupling of economic growth from carbon emissions suggests that historical relationships between macroeconomic variables and asset class performance are likely to break down. Alternative performance indicators such as carbon footprints are backward-looking and poor proxies for true climate policy exposure. These features suggest a need for detailed analysis of likely future scenarios, and risk and return within these scenarios.

This section sets out a framework and toolkit for assessing the exposure of financial assets to the climate transition in a way that directly informs portfolio construction decisions by investors. A scenario-based approach will be used to estimate the IPR's impact on:

1. macro-economic outcomes;
2. major asset classes;
3. sectors based on the Global Industry Classification Standard (GICS); and
4. specific asset within asset classes – company level.

Impacts are quantified using a layered approach[38]:

1. First, the effects of the IPR on GDP, sectoral GVA and inflation are assessed using macroeconomic and energy system models; the results are used to assess the implications for strategic asset allocation.
2. A combination of sector-level analysis and micro-economic modelling is then used to assess impacts at the industry-level based on the GICS.
3. Next, climate winners and losers will be identified at the individual asset level based on relative carbon exposure (negative and positive) and other firm-level indicators in order to determine potential impacts both at the sector and company level.
4. Finally, the first and second layers come together in an aligned assessment of changes in mean return and volatility (risk) for each asset class.

Overview of approach

The approach combines macro-economic, sector and micro-economic company level modelling to estimate the impacts on portfolio construction. This modelling will produce outputs that can be used for Strategic Asset Allocation decisions (see Figure 4 – Proposed Asset Allocation Categories from the SAA section):

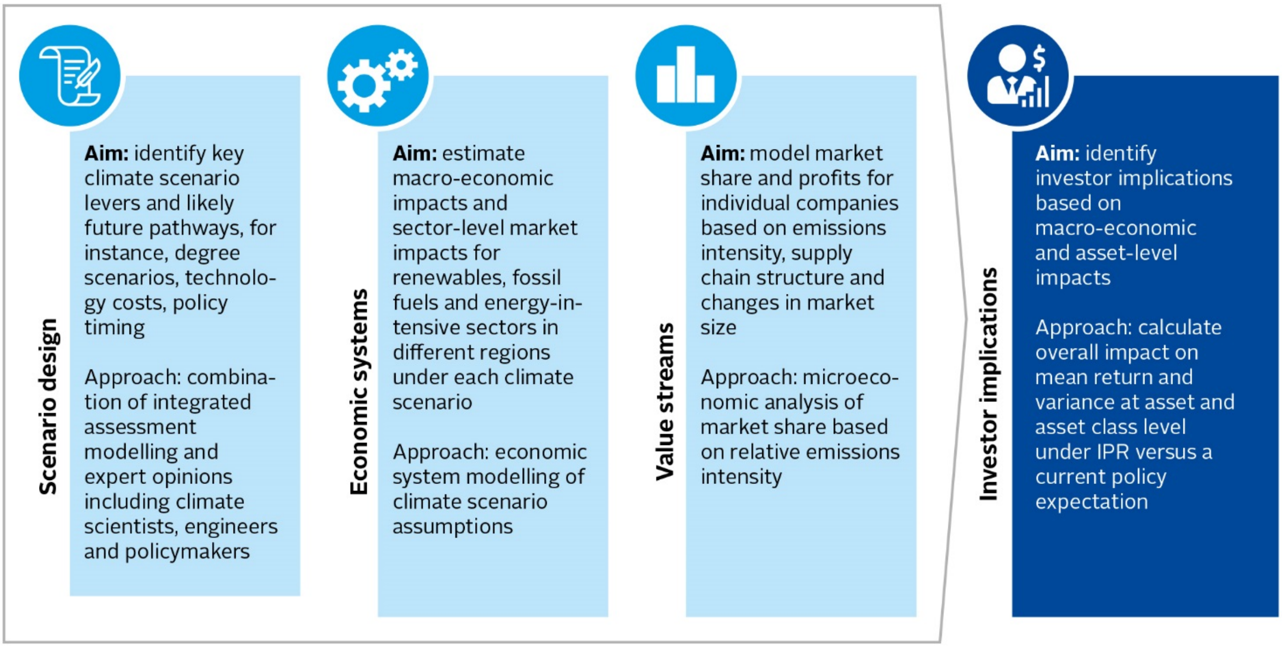
1. **Economic system modelling:** estimate GDP, inflation, interest rate, energy and other climate-relevant product and service demand, and the size of emissions-intensive and low-emissions industries within the chosen climate scenarios, using macro-economic and energy system models
2. **Value stream models:** find individual asset-level impacts from market size impacts such as demand profiles; these can be mapped to company, sector and through that asset class levels: value stream

[38] This approach is for climate transition (policy and technology) exposure only and does not seek to estimate the financial impacts of physical damages from climate change.

models include asset stranding analysis, microeconomic models of competition, and models of clean technology market share

This analysis is then translated into investor implications as illustrated in Figure 8.

Figure 8. **Summary of the approach**



Source: Vivid Economics

The modelling will produce two layers of internally-consistent data that can be used for strategic asset allocation decisions and portfolio construction.

The first layer will consist of macro-economic outcomes under different climate action scenarios over time. While the aggregate shock of an inevitable policy response on a diversified portfolio may be moderately small, there are potentially significant differences across countries and sectors. Moreover, the aggregate shock could be large over specific periods. To inform investors, the modelling provides investors with macro-economic impacts across countries and sectors over time and under a variety of potential scenarios as we have set out. In broad terms, asset allocations based on the macro-economic outcomes under committed policies (NPS) would underperform in a more ambitious climate scenario.

Table 3. **Macro-economic impacts of climate action scenarios**

Macro variables	**Committed policy scenario**			**Orderly well below 2°C scenario/s**			**IPR scenario/s**		
	2020-2025	**2026-2030**	**2031-2035**	**2020-2025**	**2026-2030**	**2031-2035**	**2020-2025**	**2026-2030**	**2031-2035**
Average GDP growth									
Country X									
Country Y									
…									
GDP volatility									
Country X									
Country Y									
…									
Ave. sector growth									
Sector A									
Sector B									
…									
Average inflation									
Country X									
Country Y									
…									
Inflation volatility									
Country X									
Country Y									
…									
Commodity prices									
Commodity A									
Commodity B									
…									

Note: *Macro-economic indicators can be presented as continuous timeseries*

Source: Vivid Economics

The second layer of value analysis will feed into asset-class performance, which will not only vary with climate ambition level, technology cost and policy timing, but also vary based on the specific characteristics of individual assets as they map up into companies and sectors. In broad terms, investors with asset allocation strategies based on current committed policies (NPS) would be worse off in certain companies and sectors and better off in others when climate action is more ambitious that this expectation. This will include differences in performance across asset classes and sub-asset classes such as sectors, as well as differences in performance within asset classes based on specific characteristics such as the geographic location, age, and technology associated with an individual asset.

Combining the two layers of outputs allows a comprehensive estimate of mean returns and risks for key asset sub(classes) across climate scenarios. This estimate can be conducted for completely passive portfolios by informing mean-variance optimization procedures across asset classes. It can also be conducted to examine potential ‘enhanced beta’ or ‘alpha’ allocation strategies where differing performance at the asset level is used to re-weight (sub)asset class composition, or to potentially create new asset classes (e.g. a low-carbon asset class).

This paper sets out what the IPR could entail and further work during the intended research programme will be needed to construct policy pathways and estimate their impact on financial markets.

References

Asselt, Harro van, and Thomas Brewer. “Addressing Competitiveness and Leakage Concerns in Climate Policy: An Analysis of Border Adjustment Measures in the US and the EU.” *Energy Policy* 38, no. 1 (2010): 42–51. https://doi.org/10.1016/j.enpol.2009.08.061.

Cai, Yongyang, Timothy M. Lenton, and Thomas S. Lontzek. “Risk of Multiple Interacting Tipping Points Should Encourage Rapid CO2 Emission Reduction.” *Nature Climate Change* 6, no. 5 (2016): 520–25. https://doi.org/10.1038/nclimate2964.

Carbon Market Watch. “Pricing Carbon to Achieve the Paris Goals.” Brussels, Belgium, 2017.

CDP. “Carbon Pricing Corridors,” 2018.

Energy Transition Advisors. “Thermal Coal in Asia – Stopping the Juggernaut,” no. October (2016): 1–89.

Green, Fergus. “The Logic of Fossil Fuel Bans.” *Nature Climate Change* 8, no. 6 (2018): 449–51. https://doi.org/10.1038/s41558-018-0172-3.

Green, Fergus, and Richard Denniss. “Cutting with Both Arms of the Scissors: The Economic and Political Case for Restrictive Supply-Side Climate Policies.” *Climatic Change*, 2018, 1–15. https://doi.org/10.1007/s10584-018-2162-x.

Griscom, Bronson W., Justin Adams, Peter W. Ellis, Richard A. Houghton, Guy Lomax, Daniela A. Miteva, William H. Schlesinger, et al. “Natural Climate Solutions.” *Proceedings of the National Academy of Sciences* 114, no. 44 (2017): 11645–50. https://doi.org/10.1073/pnas.1710465114.

Guivarch, Céline, and Joeri Rogelj. “Carbon Price Variations in 2°C Scenarios Explored.” Paris, France, 2017.

Johnson, Nils, Volker Krey, David L. McCollum, Shilpa Rao, Keywan Riahi, and Joeri Rogelj. “Stranded on a Low Carbon Planet - Implications for the Phase out of Coal Power Plants.” *Technological Forecasting and Social Change*, 2014. https://doi.org/10.1016/j.techfore.2014.02.028.

Kemp, Luke. “US-Proofing the Paris Climate Agreement.” *Climate Policy* 17, no. 1 (2017): 86–101. https://doi.org/10.1080/14693062.2016.1176007.

McGlade, Christophe, and Paul Ekins. “The Geographical Distribution of Fossil Fuels Unused When Limiting Global Warming to 2°C.” *Nature* 517, no. 7533 (2015): 187–90. https://doi.org/10.1038/nature14016.

Nordhaus, William. “Climate Clubs: Overcoming Free-Riding in International Climate Policy.” *American Economic Review* 105, no. 4 (2015): 1339–70. https://doi.org/10.1257/aer.15000001.

OECD/IEA, and IRENA. “Perspectives for the Energy Transition: Investment Needs for a Low-Carbon Energy System.” *International Energy Agency*, 2017.

Pauwelyn, Joost. “Carbon Leakage Measures and Border Tax Adjustments Under WTO Law.” *SSRN Electronic Journal*, 2012. https://doi.org/10.2139/ssrn.2026879.

Rockström, J., Gaffney, O., Rogelj, J., Meinshausen, M., Nakicenovic, N., & Schellnhuber, H. J. “A Roadmap for Rapid Decarbonization.” *Science* 355, no. 6331 (2017): 1269–71. https://doi.org/10.1126/science.aah3443.

Rogelj, Joeri, Michel Den Elzen, Niklas Höhne, Taryn Fransen, Hanna Fekete, Harald Winkler, Roberto Schaeffer, Fu Sha, Keywan Riahi, and Malte Meinshausen. “Paris Agreement Climate Proposals Need a Boost to Keep Warming Well below 2 °c.” *Nature*, 2016. https://doi.org/10.1038/nature18307.

Rogelj, Joeri, Gunnar Luderer, Robert C. Pietzcker, Elmar Kriegler, Michiel Schaeffer, Volker Krey, and Keywan Riahi. “Energy System Transformations for Limiting End-of-Century Warming to below 1.5 °C.” *Nature Climate Change* 5, no. 6 (2015): 519–27. https://doi.org/10.1038/nclimate2572.

Rogelj, Joeri, Alexander Popp, Katherine V. Calvin, Gunnar Luderer, Johannes Emmerling, David Gernaat, Shinichiro Fujimori, et al. “Scenarios towards Limiting Global Mean Temperature Increase below 1.5 °c.” *Nature Climate Change* 8, no. 4 (2018): 325–32. https://doi.org/10.1038/s41558-018-0091-3.

Stiglitz, Joseph, Nicholas Stern, Maosheng Duan, Ottmar Edenhofer, Gaël Giraud, Geoffrey Heal, Emilio Lèbre la Rovere, et al. “Report of the High-Level Commission on Carbon Prices,” 2017, 68.

Trull, T.W., A. R. Bowie, J. Jabour, and M. Haward. “Position Analysis: Ocean Fertilisation: Science and Policy Issues,” 2008, 1–20.

UNFCCC. “Aggregate Effect of the Intended Nationally Determined Contributions: An Update.” *Ge*, no. May (2016): 16–7126. https://doi.org/10.1093/iclqaj/24.3.577.

Contact us:
Vivid Economics Limited
163 Eversholt Street
London NW1 1BU
United Kingdom

T: +44 (0)844 8000 254
E: enquiries@vivideconomics.com

Company Profile

Vivid Economics is a leading strategic economics consultancy with global reach. We strive to create lasting value for our clients, both in government and the private sector, and for society at large.

We are a premier consultant in the policy-commerce interface and resource- and environment-intensive sectors, where we advise on the most critical and complex policy and commercial questions facing clients around the world. The success we bring to our clients reflects a strong partnership culture, solid foundation of skills and analytical assets, and close cooperation with a large network of contacts across key organisations.

:vivideconomics