# Integrated Assessment Models: what are they and how do they arrive at their conclusions?

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## Executive Summary

Integrated Assessment Models (IAMs) models are used to evaluate the technological and economic feasibility of climate goals such as the Paris Agreement's long-term temperature goal to hold global warming well below 2˚C and pursue efforts to limit this warming to 1.5˚C above pre-industrial. The results of these models are assessed in Intergovernmental Panel on Climate Change (IPCC) reports, and play a central role in the IPCC Special Report "Global Warming of 1.5°C" (SR1.5).

IAMs couple detailed models of energy system technologies with simplified economic and climate science models to evaluate different population, economic and technological pathways, allowing an assessment of the feasibility of achieving specific climate change mitigation goals.

Depending on the assumptions made as inputs to the models, and on the background information used to construct different scenarios, IAMs may also take into account additional targets such as sustainable development considerations. Many of the IAMs used in the SR1.5 evaluate options within a "cost-effectiveness" mode, meaning that a model deploys mitigation options in any region, any sector, at any time, so that overall (globally, and over the century), the warming limit is achieved at lowest cost.

The Paris Agreement's 1.5°C limit is a challenge for IAMs, pushing them to their structural and scientific limits. This was also the case for the former "hold warming below 2°C" goal. The IAMs have evolved to represent an increasingly comprehensive reflection of mitigation options and technologies to meet these challenges. They have to account for uncertainties in future energy prices and technologies, and an increased complexity of the connections between the factors being modelled.

**Despite the challenges, IAM models show that limiting warming to 1.5°C above preindustrial levels is still technically and economically feasible under a variety of different social and economic assumptions providing action begins very soon**. IAMs do, however, have limitations and an understanding of these limitations helps to infer climate-policy implications from mitigation pathways. Below we set out some of the important context and caveats in relation to understanding IAMs and their results, particularly in relation to the Paris Agreement's 1.5°C limit.

- **The way IAMs are set up, mitigating climate change is always more expensive than inaction**. In general, IAMs do not include avoided negative externalities, such as damages due to climate change or the cost of air pollution from the continued use of fossil energy, so the net costs of meeting the Paris Agreement's 1.5°C limit may be even lower than the IAMs project.

- **IAMs are designed to consider gradual changes to existing systems and are therefore not very good at capturing rapid technological advances** such as recent rapid advances in deployment of solar photovoltaics and the decreasing costs of renewable energy and energy storage, nor can they project the approach of systemic tipping points. Almost by definition, IAMs model established technologies and trends much better than newer technologies, whose future political and technological pathways are harder to predict. Behavioural changes such as lowered meat consumption would have to be assumed as external inputs to the models. IAMs often tend to a conservative view of the potential for transformational change.

  Several recent IAM scenarios do explore assumptions and novel modelling of dramatically lowered energy demand and increased energy efficiency related to lifestyle choices and large-scale deployment of new technologies beyond the energy sector, including information technology, urban development, sharing economies and healthier diets, for example. These are also assessed in the SR1.5. Such IAM studies further strengthen the already available evidence that energy demand and efficiency measures – partly available at net economic savings – are a crucial requirement for limiting warming to 1.5°C, reducing the challenges faced by supply-side measures alone and substantially enhancing the overall feasibility and sustainability of achieving the 1.5°C limit.

- **Many IAMs still include some carbon capture and storage (CCS) in their assumptions,** despite the fact that this technology when deployed with fossil fuel power plant is now widely seen as a relatively expensive mitigation option with an uncertain future. The fact that CCS is not a zero emissions technology has important implications for natural gas in the power sector, where many IAMs aimed at reaching close to zero global emissions in the power sector by 2050 still include CCS. On-going reductions in renewable energy and storage costs also means the utilisation of natural gas for power production will likely decrease below presently expected levels – and therefore present IAM models may be overestimating natural gas markets. Equally, at present IAMs do not adequately represent the rapid electrification that is taking place across many sectors - such as in industrial sectors such as steel production and the transport and building sectors.

- **The change from internal combustion engines to electric vehicles** is another example of the difficulty IAMs have in keeping up with changes in the real economy. The uptake of EVs and renewably hydrogen-powered fuel cell electric vehicles (FCEV) in the private transport and freight sector is happening much faster than seen in the IAMs' transport sector decarbonisation indicators.

- **Bioenergy represents a key area of uncertainty in IAMs**. Bioenergy is a renewable energy resource. Using biomass to generate electricity and produce biofuels, together with the capture and storage of resulting $CO_2$ emissions, can result in net-negative emissions, an important option for compensating remaining emissions from other sectors for which mitigation options may be limited, such as in agriculture required to feed a still growing global population. However, there is a wide range of estimates around limits to the sustainable potential for bioenergy use. Many IAMs already constrain climate mitigation options by considering other sustainable development needs such as food production and limiting biodiversity impacts. The complexity of bioenergy options and their implications means that IAM scenarios need to be supplemented by follow-up analyses on more specific aspects and implications of bioenergy deployment.

- **Carbon Dioxide Removal (CDR) in IAMS.** The two main CDR options represented in the IAMs underlying the IPCC 1.5°C Special Report are in the land sector – storing carbon in forests and soils via afforestation/reforestation – and, in the energy system, bioenergy in combination with CCS (BECCS). IAMs differ greatly in the extent to which CDR is implemented, again depending on other assumptions made in the inputs to the models. Some IAMs include few constraints on the use of modern bioenergy, while others only allow for it after satisfying land demand for agriculture and food, and will not touch pre-defined biodiversity hotspots, natural forests and conservation areas. IAM CDR scenarios include land-use changes, such as reversing current worldwide net emissions due to deforestation toward increasing reforestation and afforestation, to help meet climate change mitigation targets. The capacity for "nature based solutions" in meeting Paris Agreement targets is uncertain, but these can play an important role.

  The simplest summary of IAM outputs related to CDR is that the more quickly and completely decarbonisation and energy efficiency measures can be implemented and energy demand limited, and the more rapid greenhouse gas emissions are reduced in all sectors, the less need will there be for CDR.

**Overall, while IAMs are one of the essential tools for policymakers to provide guidance on technically and economically feasible pathways to achieve specific climate and sustainable development goals, they are only one component of a toolbox of analytical tools and broader considerations to be used in the evaluation of mitigation options to meet climate targets.**

# Full briefing

## Introduction

For more than 20 years, energy, economy and climate models have played a central role in evaluating the technical and economic feasibility of climate targets. These are Integrated Assessment Models (IAMs): they integrate knowledge from different domains into a single assessment.

In the context of the Intergovernmental Panel on Climate Change (IPCC) Assessments, IAMs have played an important role in framing questions around what is feasible, and what is not, in climate and energy policy terms.

Research groups involved in integrated assessment modelling have played a significant role in defining what policy scenarios can - and should - be modelled, and have responded to questions from government and other stakeholders about the feasibility of limiting warming to relatively low levels. The new RCP P1.9 scenario, which limits warming to about 1.5$^{o}$C[1], was developed after the adoption of the Paris Agreement.

IAMs have the benefit of bringing the whole social economic system together and evaluating different population, economic and technological development pathways within an internally consistent, science-based framework with a view to evaluating the feasibility of different climate and/or sustainable development goals. Many IAMs have developed in sophistication and now include considerable technological detail and coupling between different systems, including land use, forestry and agriculture. Nevertheless, as with all models there are still significant limitations and caveats, some structural and others contingent upon scientific and technological development.

The IPCC Special Report on 1.5°C, more than any previous IPCC report, is evaluating the technological and economic feasibility of limiting warming to 1.5°C. The energy modelling community finds this level of ambition – while already quite risky for the global earth system - to be a challenge for their models. It pushes IAM models to their limits in both structural and scientific terms. Under such a stringent climate target virtually every known option for mitigation has to be deployed. Models are pressed to - in effect - “choose” between the timing of deployment of options based on (future) energy price, and technological information that is inherently uncertain. And as with any mitigation pathway, there are important connections and synergies, both positive and negative, with sustainable development objectives.

Evaluating the implications of mitigation pathways for sustainable development metrics often relies upon post-processing of a model’s output. This includes, for example, co-benefits of mitigation such as reduced air pollution and improving human health and agriculture outcomes, which are not normally included in the model assessments, nor in estimation of the costs of mitigation.

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[1] Rogelj, J. et al. (2018) Scenarios towards limiting global mean temperature increase below 1.5C, Nature Climate Change, doi:10.1038/s41558-018-0091-3

[2] Where countries committed to “Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial

The overall finding of the recent scientific literature on 1.5°C compatible pathways is that this goal is still technologically within reach under a range of different social, economic and population assumptions. Not surprisingly, models find that the costs of limiting warming to this level are higher than the cost for limiting warming to 2° C – as reported in the IPCC AR5. On the other hand, the IAMs considered here do not take into account the costs climate change impacts, which will be higher for 2°C, nor economic benefits of reduced pollution from fossil fuel use.

This background paper is designed to lay out important context and caveats in relation to understanding IAMs and their results - particularly in relation to the 1.5°C issue as they will be presented in the IPCC 1.5°C SR.

## Scientific background

Integrated Assessment Models (IAMs) represent the coming together of three different worlds of scientific thinking in relation to energy and climate science: energy system/technological progress models, economic system models, and climate science models.

**Energy system models** were historically focused on making prognoses about fossil fuel and nuclear power systems, and how issues of resource supply and societal demand would balance out over time periods of a few decades, to several decades. In the context of climate change scenarios, these models have been adapted to provide more detailed modeling of longer-term developments in regional and global energy systems.

**Economic system modeling** is based on fundamental notions of how a market-based economy functions, often starting with assumptions that world markets are in equilibrium and functioning efficiently, with perfect information available to all equally-placed actors. These models can take different assumptions on future foresight, from perfect over all time foresight to what is called myopic, or short-term foresight.

**Climate science models**, as used in IAMs, integrate the physics and chemistry of the atmosphere, carbon cycle and the ocean, in reduced complexity models designed to translate greenhouse gas emissions and air pollutants to GHG concentrations, radiative forcing and temperature, and other large-scale physical changes in the climate system.

The core idea of IAMs is to capture the interactions between socioeconomic, technological and natural systems by combining simplified economic and climate models with more detailed modeling of regional and global energy systems to make relevant projections of the consequences of climate policy choices.

Their scenarios describe an internally consistent and calibrated way for regional energy systems to get from current developments to meeting long-term global climate goals like 1.5°C. Scenarios reflect a number of factors: regional diversity, (future) GDP and population developments, supply and demand of fossil fuel and renewable energy carriers, technological potentials and developments, structural change, autonomous and price-induced energy efficiency changes, energy resources and reserves, inter-fuel substitutions, economies of scale, imports, exports, etc., all affecting prices and ultimately allowing us to find an “optimal” prioritisation of mitigation options.

From its starting point to end-of-century, a model deploys mitigation options in any region, any sector, at any time, so that overall (globally, and over the century), the temperature goal is achieved *cost-effectively*. This is why the outputs of these models are often referred to as "least-cost" pathways; as opposed to trying to compare costs and benefits of mitigation action, the IAMs considered here taken a temperature limit as a given externally determined parameter. However, the models also allow the assessment of a large variety of explicit constraints that make their results more realistic or desirable in some way, for example by scaling up ambitious climate action in some regions with a delay compared to the cost-effective solution, or by putting limits on the use of modern bioenergy.

## IAMs and the Paris Agreement

Some background is needed to set the stage for placing IAM results in the context of the Paris Agreement (PA)[2]. The specific PA limit on global temperature increase can be assessed by IAMs in terms of how to achieve this in a cost-effectiveness mode. Interestingly, many IAMs of a previous modeling generation (from, say, 5-10 years ago) could not find within their own modeling structure economically viable solutions to limit warming to 2 or 1.5°C.
As both scientific understanding of the impacts of different temperature changes have been recognised, and the sophistication of IAMs increased, more stringent limits have become "feasible." IAMs are now able to trace out energy system transformation pathways that lead to 1.5°C-compatible scenarios. In addition, real-world developments such as decreasing costs of renewable energy technologies have increased the palette of economically viable mitigation options. These changes in the ability of models to find cost-effective solutions to achieve climate goals represent an interesting and cautionary dynamic. Models of any kind are only as good as their input assumptions, from those about up-to-date technological and market developments to the more fundamental questions of how "rational" people and governmental policies will be.

Given this introduction, what do IAMs now tell us in more detail about the potential for achieving the PA goals? We illustrate how IAM results can be understood by discussing five pertinent topics.

## 1. Economic costs of mitigation

Starting with the "rational" assumption that the economic system is already in an optimum state, at least for the sake of argument, IAMs first determine the "business-as-usual" pathway for different future scenarios of socioeconomic development.

Then, by changing to a lower "allowed" total carbon budget, lower greenhouse concentrations reached by end of century, or by setting a carbon price on carbon dioxide emissions, the model calculates the optimal, least-cost pathway from the business-as-usual, or reference case, under these new constraints.

By definition, this method with these models will *always* find that the new situation (e.g. Paris Agreement target) costs more than "business-as-usual." We know that economic rationality is not universally the case – for example while it is not economically efficient for

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[2] Where countries committed to "Holding the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognising that this would significantly reduce the risks and impacts of climate change."

governments to subsidize the extraction and use of fossil fuels, in reality, they do. At the same time, it would be economically rational for governments, or more generally, ideal market-based mechanisms, to add the negative external costs of fossil fuel consumption (e.g. air pollution costs, environmental damages) to the price consumers pay for energy from these sources; again, for the most part, they do not.

IAMs do not usually take either of these factors sufficiently into account. Even so, IAMs find the costs to get onto a Paris Agreement pathway are quite low - a fraction of a percentage point of GDP per year. In the case of 2°C targets reported in AR5, the average was 0.06%/year – barely distinguishable from the noise of real-world GDP fluctuations.

Recent IAM pathways (Rogelj et al 2018) find time-averaged discounted reductions in global GDP associated with mitigation measures for 1.5°C (compared to a no-climate-policy baseline) to be three times higher than for 2°C in the long term. GDP losses would be three to four times higher in the next few decades due to the greater need for rapid, near-term reductions in 1.5°C pathways. These GDP losses would still be very small compared to projected overall GDP growth. Also, they do not account for larger and earlier benefits of 1.5°C compared to 2°C in terms of the reduced climate change damages – or the larger co-benefits from lower pollution related to fossil fuel extraction and use.

## 2. 1.5°C pathways under the recent and continuing drop in the price of renewables

IAMs have a difficult time projecting emissions pathways for a future of dramatic changes. This is not surprising, as such changes are almost by definition surprising and rapid, and are often recognised only in hindsight as having been a true transition. If government policies or personal preferences nudge behavior toward a "tipping point", a rapid change in energy consumption could be possible, one that would be difficult to replicate in IAMs that are predicated on slow, smooth, marginal changes.

For example, IAMs have been "surprised" in recent years by the dramatic cost improvements of renewable energy technologies compared to fossil fuels. A large part of this cost development has been due to behavior by consumers, and by governments deciding that more solar panels, wind turbines and, more recently, batteries and electric vehicles, would be a good long-term policy to support – not because those actions were inherently the most rational and optimal decisions. The resulting sharp increase in installations and purchases induced both learning and scale effects that drove down costs, making further installations even more attractive – a "virtuous cycle".

In fact, IAMs are beginning to find solutions that are optimal under the conditions of the model over the long-term and that move toward much higher shares of renewables in electricity than was the case even a few years ago, with results in the most recent models reaching 60-80% non-biomass renewable electricity by 2050.

Whereas 2°C scenarios at the time of IPCC's Fifth Assessment Report (2014) projected that about 5-17% of global electricity supply would be covered by solar PV by mid-century, Creutzig et al (2017) explicitly updated an IAM with the very recent drop in solar photovoltaics (PV) prices. They showed that the updated projections lead solar PV meeting 30-50% of global electricity generation by mid-century –assuming further advances in system integration of renewables. Bottom-up sectoral studies still generally find even stronger emissions-reduction potential at the same or lower cost for the near term than realised in IAMs (UNEP 2017).

## 3. Fossil fuel phase out and CCS

Unsurprisingly, the difference between 2°C and 1.5˚C scenarios is that the 1.5˚C scenarios require an even more rapid decarbonisation of the energy system, with global zero $CO_2$ emissions being achieved around the 2070s with 2˚C, but around the 2050s for 1.5°C compatible pathways, with coal phased out even earlier (before 2050) than other fossil fuels.

In IAMs, a new technology is scaled up most easily if it is very similar to older, known technologies and, in this context, to many in the modeling community adding carbon capture and storage (CCS) to fossil fuel power plant appeared to be a more logical and cost-effective step for the model than a change to a new technology, such as utility scale PV or even massive deployment of distributed rooftop solar photovoltaics (PV).

In this context, many IAMs produced results that indicated CCS from fossil fuels power plants were a very promising option. In practice, however, the costs of this technology were higher than estimated and its feasibility proved more difficult: progress toward commercialising the technology has been much slower than projected ten years ago. As a consequence, fossil CCS is now widely seen as a relatively expensive mitigation option with an uncertain future. However, many IAM models have continued to deploy this technology for fossil fuel power plants at large scale over the 21st century in both 1.5°C and 2°C pathways. Model deployment of fossil CCS is lower in 1.5°C pathways as it is not a zero emissions technology and is estimated to achieve only 85-95% reduction when 100% reductions are needed by 2050.

This has important implications for policy, for example with natural gas in the power sector and undermines the commonly-advanced argument that gas is a bridging fuel. It is quite common to see natural gas deployed in the IAM model assessments aimed at reaching close to zero global emissions from the power sector by 2050; however, in such pathways natural gas is often accompanied by deploying CCS. As renewable sources of power increase in scale, the utilisation rate of natural gas power plants decreases, making the addition of CCS an even more expensive proposition.

Given the recent developments in renewable energy and storage technologies, some of which have yet to be included in state-of-the-art IAMs, it would seem unlikely that CCS could be economically deployed for natural gas power turbines, with the implication that present IAM models may be overestimating future natural gas markets for the power sector.

Another important factor is that at present IAMs do not adequately represent the rapid electrification across many sectors that seems increasingly plausible to many analysts, particularly in industrial sectors such as steel production, in the transport sector (see below) and in the buildings sector (Kriegler et al 2018; Grubler et al 2018). Implementation of the associated technologies would allow for an even more rapid phase-out of fossil fuel emissions, without relying on CCS.

## 4. Uptake of electric vehicles – electrification of transport

The change from internal combustion engines to electric vehicles are another example of the difficulty IAMs have in keeping up with likely changes in the structure of the complex world energy system. In a parallel with renewables in electricity generation, the uptake of EVs and renewably hydrogen-powered fuel cell electric vehicles (FCEV) in the private transport and freight sector has recently been faster than expected, and is expected to speed up in the coming decades. This is all happening much faster than in the IAMs' transport sector decarbonisation indicators.

IAMs try to capture a change in the transportation system where low-carbon alternatives such as biofuels, hydrogen and electric vehicles displace internal combustion engine vehicles. The technological change is reflected in a gradual decrease in consumption of oil (thus decreasing $CO_2$ emissions), coupled with an increase in the use of biomass and electricity. However, what the models don't usually capture well - if at all - would be the answers to questions such as "what will the share of electric vehicle sales be in 2030?" or "how many EV charging stations must China build by 2030 to support the electrification of personal vehicle transportation?"

Finding details of pathways within individual sectors that might still be compatible with the overall global, Paris Agreement-compatible total emissions profile requires an additional effort of downscaling the high-level results of IAMs, while also taking into account developments that have made faster progress than initially anticipated.

## 5. Demand-side and energy efficiency measures

Traditionally, supply-side management of the energy system is represented at the highest level of detail in IAMs and, alongside technological energy efficiency improvements that lower energy demand, is their strongest aspect. Less well covered by IAMs, and therefore less represented in the scenarios they produce, are fundamental interventions on the demand side, which were usually explored through simplified variations in underlying assumptions.

This is starting to change, however, with some of the recent publications covered in the IPCC Special Report on 1.5°C. These explore elements and synergies related to, for example, behavioral changes and lifestyle choices, leading to fundamental shifts in transport modes, in diets towards low meat consumption, or low population growth (van Vuuren et al 2018, Grubler et al 2018).

These variations generally facilitate a more rapid near-term decarbonisation, enhance sustainability synergies of 1.5°C pathways and may lower the need for Carbon Dioxide Removal (see next section), with the caveat that the authors cited above do not necessarily deem it plausible that all such changes would materialize simultaneously to the extent the most far-reaching of these scenarios assume.

## 6. Carbon Dioxide Removal

As a final example of IAM output we look at the question of Carbon Dioxide Removal (CDR), or negative emissions. The need for negative $CO_2$ emissions arises for several reasons. First, today's high $CO_2$ concentrations from historical emissions mean that we need extreme rates of $CO_2$ emission reductions to halt the rise in $CO_2$ concentration. To reduce $CO_2$ concentrations in order to meet the Paris Agreement's temperature limit, we will have to take some $CO_2$ out of the atmosphere.

Second, there are significant non-$CO_2$ greenhouse gas emissions that are difficult to reduce, notably from agriculture and some industrial sources. For example, a growing population means it will be quite a challenge to just stabilize non-$CO_2$ emissions from agriculture in the next few decades. Reducing more non-$CO_2$ greenhouse gas emissions will require fewer negative $CO_2$ emissions, and vice versa.

Thirdly, we cannot just switch energy systems overnight, and significant time will be needed to move to a low carbon energy system. The faster we can do this, the more we can reduce the need for negative $CO_2$ emissions, and conversely, the slower our action, the greater the need for negative $CO_2$ emissions.

Taken together, it is very difficult to see how CDR can be completely eliminated from the mix of climate change mitigation options and still achieve the PA target.

The two CDR options represented in the IAMs underlying the IPCC 1.5°C Special Report are in the land sector – storing carbon in forests and soils via afforestation/reforestation, including ecosystem restoration – and, in the energy system, bioenergy in combination with CCS (BECCS). In typical scenarios, these are roughly deployed in equal measure, except with scenarios that reach very high levels of CDR, exhausting the limited potential of afforestation/reforestation.

IAMs differ greatly in the extent to which CDR is implemented, again depending on other assumptions made in the inputs to the models (such as population size and socioeconomic conditions), and in the expected speed of transformation in socioeconomic and technological trends represented in the models.

For example, some IAMs include few constraints on the use of modern bioenergy, while others only allow for it after satisfying land demand for agriculture and food, and will not touch pre-defined biodiversity hotspots, natural forests and conservation areas.

Also available are 1.5°C pathways that set hard limits on the total amount of modern bioenergy deployed, restricting these to levels considered likely to be met by the more sustainable bioenergy options available, such as a limit of around 100 EJ/year, about two times the present-day use of bioenergy in the global energy mix. These are important considerations given the ongoing discussion on the sustainability of large-scale deployment of bioenergy and concerns related to food security.

Because IAMs have a limited level of detail in bioenergy options, the identified demand for it in IAM scenarios is best supplemented by follow-up analyses that assess a wide portfolio of bioenergy feedstocks to meet the total demand - in light of their various characteristics and sustainability implications. Such a portfolio could include, for example, bioenergy grown on marginal agricultural land, the use of agriculture and forest residues and maximised synergies with soil restoration, and would exclude as much as possible dedicated bioenergy crops on productive agricultural land, as well as options that decrease forest area.

The simplest summary of IAM outputs related to CDR is that the more quickly and completely decarbonisation and energy efficiency measures can be implemented and energy demand limited, and the more rapid greenhouse gas emissions are reduced in all sectors, the less need will there be for CDR.  A simple way to balance near-term reduction targets with the desirability of limiting future reliance on CDR is to base such targets on 1.5°C pathways with limited overshoot: even if the level of peak warming in the 21st century exceeds 1.5°C before dropping down again, this peak warming should be very close to 1.5°C. If one applies a selection criterion of a maximum "overshoot" below 0.1°C (i.e. peak warming below 1.6°C), only pathways with limited CDR will qualify.

## Conclusion

A key point of any economic model is balancing trade-offs between choices. Economics is the study of scarcity, including that of atmospheric space to safely absorb greenhouse gas emissions, natural resources, and other factors. By accepting the Paris Agreement and its stringent targets, there is a recognition that net carbon dioxide and other emissions must be reduced to zero, or even below, within a generation.

Thinking in terms of a total carbon budget for global industrial civilisation over the past two hundred years, there are only a few choices available to limit temperature increases. We can choose to strictly remain within that budget, eliminating emissions from all of our activities, including not only the energy systems discussed so far, but also agriculture, aviation and industrial processes (*e.g*. cement production), and turning the land sector into a net $CO_2$ sink.

Alternatively, we can reduce emissions to the extent possible, continue with relatively small amounts of emissions from sectors that are difficult to decarbonize (meat and rice production), use land management options for CDR as much as possible, and then use technological means to capture and store carbon dioxide (CCS) in stable underground reservoirs. The goal of IAMs is to explore these alternative pathways and to present options for transformation under different scenarios.

IAMs do provide useful information for policy makers and help guide the thinking of other institutions and groups. In an integrated view of sustainability, the economy forms one subset of society, and global societies must function within the planetary boundaries set by natural systems. Following that line of thought, and as has been discussed in this Brief, IAMs provide one tool, with strengths and weaknesses, in what should be a toolbox of measures, policies and broader considerations of how to shape the future of the energy system and climate change mitigation, and of sustainable development policies.

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