REVISITING THE CLIMATE STABILISATION WEDGES: A FRAMEWORK FOR DECARBONISING THE ECONOMY BY 2050

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Overview

Integrated assessment models (IAMs) are the primary tool used for producing scenarios of future decarbonisation, but their utility has been the subject of fierce debate. Critics of IAMs often point to their opacity and overwhelming complexity, which have led to distrust among scenario users and made their results difficult for broad audiences to comprehend [1]. As criticisms of IAMs appeared, so too did alternative frameworks for modelling climate change mitigation. The most well-known framework is the Stabilisation Wedges introduced by Pacala and Socolow [2]. It contrasted two fifty-year futures: business as usual (BAU) and stabilisation. Under the BAU trajectory emissions increase linearly from 7 to 14 Gt C yr^{-1} between 2004 and 2054, while under the stabilisation trajectory emissions plateau at 7 Gt C yr^{-1}. Situated between these trajectories is a triangular emissions gap of 175 Gt C or 7 Gt C yr^{-1} in 2054. No single technology could feasibly halve BAU emissions within 50 years, so the emissions gap is divided into seven stabilisation wedges. Each wedge represents an activity that reduces emissions, starting from zero in 2004 and increasing linearly to 1 GtC yr^{-1} of avoided BAU emissions in 2054. For Pacala and Socolow, 'solving the climate problem over the next fifty years' meant 'filling' all seven wedges. They proposed fifteen mitigation options, ranging from wind power to forest management, and quantified how widely each must be deployed to fill a wedge. With more options than wedges, the framework allowed its users to construct their own mitigation pathway.

The simplicity, transparency and flexibility of the Stabilisation Wedges resonated with a very broad audience, as evidenced by its widespread use in education and its continued use in academia. Yet, much has changed in the 18 years since the framework was published – emissions continued to rise, temperature targets became more ambitious, and the portfolio of mitigation options expanded. This paper revisits the wedges framework to update its timeframe, ambition, and scope. It explores how many wedges must be achieved between 2020 and 2050 to limit global warming, and evaluates how widely an expanded list of 36 mitigation options must be deployed to achieve a wedge.

Methods

Our methodology is divided into four steps. Firstly, we modify the wedge's timeframe to cover the years 2020-2050. This shorter timeframe alters the dimensions of a wedge, and so the required annual emission saving is reduced from 1 Gt C (3.67 Gt CO_2) to 2 Gt CO_2. This retains the wedge's gradient (i.e., rate of deployment) and allows us to include important mitigation options that do not have the potential to achieve a 1 Gt C saving in 2050. Secondly, we establish the relationship between the number of wedges achieved and end-of-century warming. As wedges only run to 2050, the relationship between cumulative emissions in 2020-2050 and warming in 2100 is derived from ~400 scenarios from the IAMC database (Figure 1a). Thirdly, we scope mitigation options with the potential to achieve a wedge, based on previous assessments of their technical potential. Finally, we apply a standardised method to evaluate the effort required to achieve a wedge from each option. Like Pacala and Socolow, we calculate the emissions avoided per unit of a reference practice (e.g., a conventional car or fossil power plant) that is displaced by a mitigation practice (e.g., an electric car or wind turbine). The emissions avoided per unit are then used to determine how widely a mitigation option must be deployed to achieve a 2 Gt CO_2 yr^{-1} saving in 2050. A major advance is that we use four reference scenarios to account for uncertain reference assumptions (e.g., vehicle kilometres travelled or the fossil generation mix) which affect the effort required to achieve a wedge.

Results

Figure 1a shows that the relationship between cumulative emissions in 2020-2050 and end-of-century warming is non-linear – below ~1,100 Gt CO_2 (roughly 2°C) there is a downtick in the temperature increase per unit of CO_2 emitted. This is because in scenarios with lower cumulative emissions in 2020-2050 emissions tend to reach net zero before 2100. At net zero emissions warming ceases, and so scenarios that reach net zero before 2100 have more similar warming outcomes than less ambitious scenarios that do not reach net zero before 2100. Figure 1b shows how this relationship influences the median warming outcome of different wedge trajectories. The first (top) ten wedges have the greatest impact on warming (0.12°C per wedge), while the final (bottom) ten wedges have a smaller impact on warming (0.04°C per wedge). Relative to the no policy (4°C) scenario, 20 wedges are required to limit warming to 2°C or 33 wedges for 1.5°C. Current policies, if delivered in full, would contribute roughly 12 wedges and limit warming to 2.6°C, requiring a further 8 wedges to limit warming to 2°C or 21 wedges for 1.5°C.

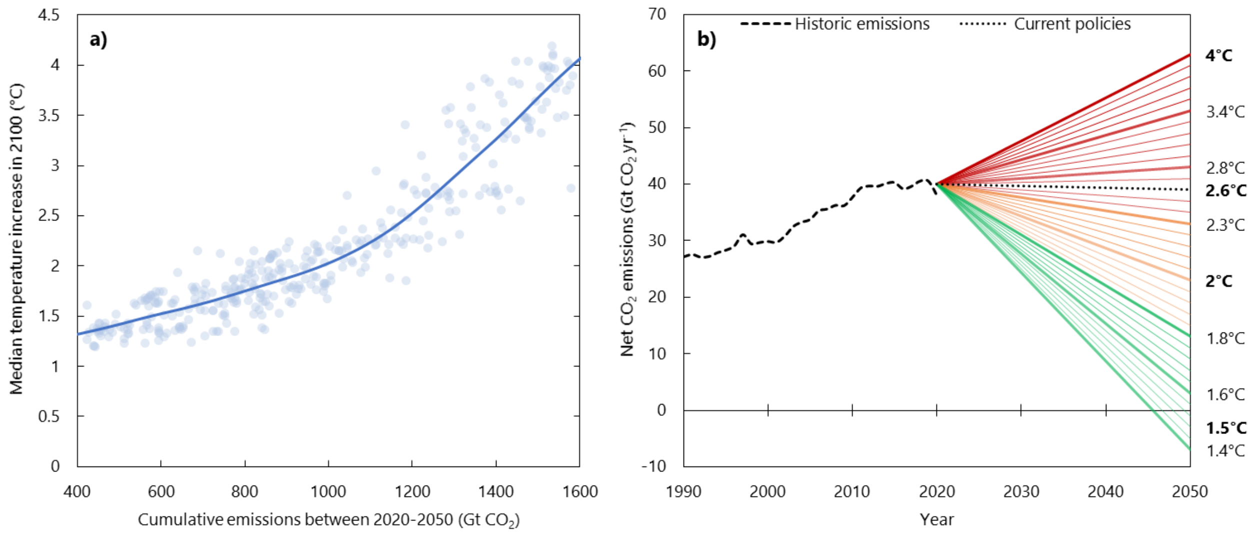

Figure 1. (a) Relationship between cumulative CO_2 emissions (2020-2050) and median end-of-century warming. Points represent scenarios from the IAMC database, and the line shows the LOESS regression fit. **(b)** Median end-of-century warming for emissions trajectories in which different numbers of wedges are achieved relative to a no policy (4°C) scenario and a current policies (2.6°C) scenario based on the IEA's Stated Policy Scenario [3] .

Table 1 shows the additional effort required to achieve a wedge from a sample of 10 of the 36 mitigation options evaluated in our analysis. The results highlight the enormous effort that is required to achieve a wedge from any mitigation option. Some options (e.g., wind and solar power) have the potential to contribute multiple wedges if recent trends continue, while others (e.g., avoided air travel) are unlikely to yield even one wedge. CCS, BECCS, and DAC are not yet deployed at any meaningful scale and will need to gain traction quickly to achieve a wedge.

Table 1. Additional effort required to achieve a wedge from a sample of mitigation strategies. The additional mitigation effort reported is the mean effort across our four reference scenarios.

Strategy	Additional effort required to achieve a wedge by 2050 (2 Gt CO_2e yr^{-1})
1. Build more wind farms	Build 1,100 GW of onshore or 800 GW of offshore wind capacity (1.5 or 24 times current installed capacity respectively).
2. Build more solar farms	Build 2,000 GW of solar PV capacity (3 times current installed capacity).
3. Build new CCS plants	Build 500 GW of efficient coal or gas CCS power plants with 90% capture.
4. Deploy more EVs	Drive efficient EVs with low-carbon electricity for one-third of conventional car trips projected for 2050 (900 million EVs compared with 10 million today).
5. Avoid air travel	Reduce passenger flights projected for 2050 by 70% (to 670 km per capita per year).
6. Deploy more heat pumps	Deliver 5,000 TWh of heat to buildings using efficient heat pumps with low-carbon electricity (three times the heat delivered by heat pumps today).
7. Insulate buildings	Reduce average building heat loss from 1.2 to 0.8 W m^{-2} K (compared with 1.5 W m^{-2} K today). Insulation rates must improve by 2.3% per year compared to 0.8%.
8. Deploy industrial CCS	Install CCS with 90% capture at 80% of Basic Oxygen steel mills or 90% of cement plants projected for 2050.
9. Deploy BECCS	Build 280 GW of efficient BECCS power plants. This would require 19 EJ of cultivated grass (40% of today's total bioenergy supply).
10. Build DAC plants	Build 500,000 Orca-scale solid sorbent DAC plants (~50 per day for 30 years), powered using heat pumps and low-carbon electricity (requires 5% of today's global electricity supply).

Conclusions

The Stabilisation Wedges are one of the best-known concepts in energy and climate research. While the conceptual framework remains useful, the context in which it operates has changed dramatically. By updating and extending the framework, we provide a transparent and widely accessible perspective on the scale of the mitigation challenge that lies ahead and the portfolio of mitigation options available for meeting that challenge.

References

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[3] IEA, World Energy Outlook 2021, Paris, 2021.