The International Energy Agency and the Paris Goals: Q&A for Investors

Briefing by Oil Change International
and Greenpeace UK
January 2019

Summary

The International Energy Agency (IEA) is the world's most influential provider of energy information. Its flagship *World Energy Outlook (WEO)* projects energy supply and demand to 2040, under three different scenarios. Investors often use the *WEO* to assess energy investments.

Contrary to the IEA's claims, its **'Sustainable Development Scenario' (SDS)** is not aligned with the Paris goals. Using the SDS (or any other IEA scenario) to assess the climate-robustness of energy investments may understate the degree of transition risk. The SDS does not give a useful guide to the decisions and actions needed to achieve the Paris goals, on either fossil or clean energy. Investors are increasingly engaging the IEA in order to address this gap.

The SDS replaced the IEA's '450 Scenario' (450S), introduced in 2008, which aimed for a 50% probability of keeping warming below 2 degrees Celsius (°C), and which the IEA acknowledged was not aligned with the Paris goals. However, the SDS has the *same emissions profile* as the 450S. Rather than updating its ambition to reflect the 2015 Paris Agreement and the latest science, the IEA has instead just changed how it interprets the scenario.

This briefing explains the details, including an overview of the latest *WEO*[1] of November 2018, discussion of what the IEA says about the SDS, and a review of other IEA scenarios including the Beyond 2 Degrees Scenario.

The IEA's new interpretation of the SDS/450S is based on comparison with emissions reduction scenarios that rely on very large-scale deployment of 'negative emissions' technologies, of which the IEA has said "the prospect is remote." This briefing compares the SDS only with those scenarios that do not rely on negative emissions to a greater extent than their realistic potential, based on assessments in the Intergovernmental Panel on Climate Change's (IPCC's) recent special report. It finds that the SDS is aligned with 2°C of warming; it does not give a guide to aiming "well below" 2°C or "pursuing efforts" for 1.5°C as stated in the Paris goals.

The problem has an easy solution, which was proposed by the IEA itself in 2016 but not implemented: to use two scenarios, one for 1.5°C and one for 2°C. Energy decisions should then aim to get as close as possible to the 1.5°C scenario, and as far below the 2°C scenario as possible. This range would also give a fuller picture of energy investments potentially at risk from action on climate. The IEA should also revert to its precautionary approach to the future availability of unproven negative emissions technologies.

This briefing recommends how investors may help deliver this solution by engaging the IEA. The IEA is now prioritising engagement with investors, as a key user group of its *WEO*. We recommend that:

Investors should individually and collectively engage the IEA to express their scenario needs. In particular:

- **The SDS should be updated to reflect the Paris goals, with scenarios reflecting both 1.5°C and 2°C, as the IEA proposed in *WEO 2016*.**
- **The scenarios should revert to the IEA's previous precautionary assumption, that 'negative emissions' technologies may not become available at large scale.**

In the meantime, this briefing recommends other sources of information that investors can use, including from the IPCC and commercial providers.

Why should investors be concerned about the IEA?

IEA scenarios are not aligned with the Paris climate goals, so using them to assess the robustness of energy investments may understate the degree of transition risk. They do not give a useful guide to the decisions and actions needed to achieve the Paris goals.

Through initiatives such as the Climate Action 100+,[2] and following the recommendations of the Task Force on Climate-Related Financial Disclosures (TCFD),[3] investors are increasingly testing the robustness of portfolios in climate-constrained scenarios. Often, such stress-tests use the IEA's **'Sustainable Development Scenario' (SDS)**. (Sometimes the IEA's Beyond 2 Degrees Scenario is used – this is discussed on page 9).

When investors ask fossil fuel companies about how their strategy incorporates climate risk, it is often to the SDS or related scenarios that the companies point. Companies including ExxonMobil, Shell, Chevron, BP, Total, Glencore and BHP Billiton have used the SDS to claim that they do not need to change course and that investments are not at risk.[4]

This can make a very big difference. In the report *Off Track*,[5] Oil Change International used Rystad Energy's UCube database to create cost curves for oil and gas[6] and plotted where they intersect with the demand levels in IEA scenarios, to reveal which production will be competitive at those levels. We also plotted demand levels corresponding to the carbon budgets published in the IPCC's *Fifth Assessment Report*, for a 66% probability of keeping warming below 2°C and for a 50% probability of keeping it below 1.5°C.[7] This is shown for oil in Figure 1. As can be seen, the lower demand levels would imply a considerably lower oil price, and hence much greater risk in upstream oil investments.

Using Rystad UCube estimates of the investment in the competitive portion of production, the analysis finds that between 70% and 94% of the investment under the SDS – $7.3 to $9.9 trillion – is incompatible with the Paris goals.[8] Conversely, investment levels in non-fossil fuels will be correspondingly lower in the SDS than the Paris goals would require. As such, the SDS may encourage under-investment in the low-carbon economy and over-exposure to fossil fuels.

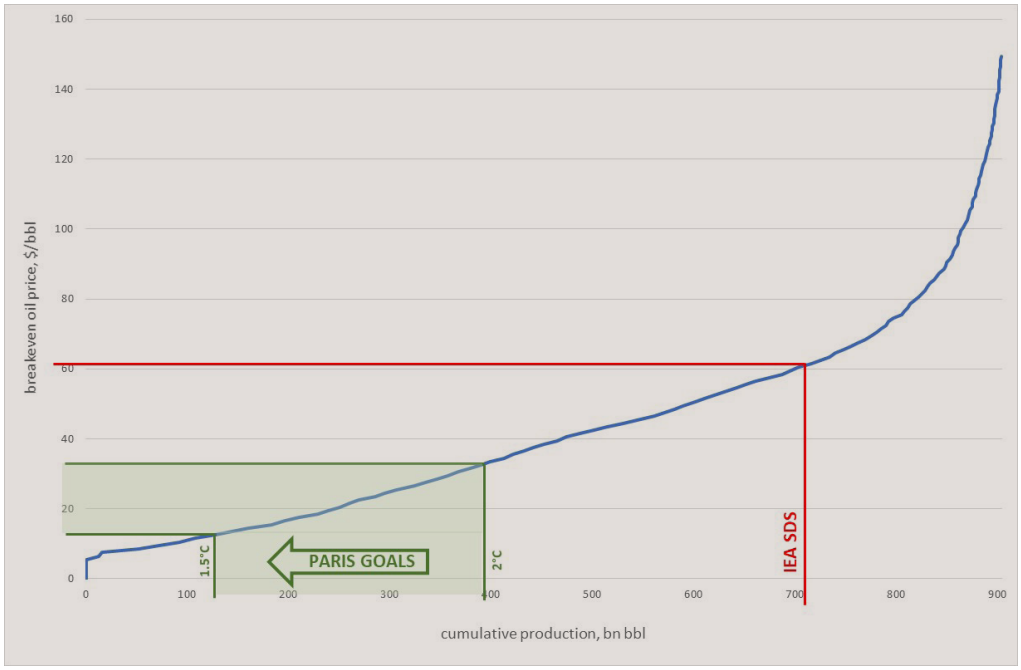

Figure 1: Oil Cost Curve: Cumulative Production 2018 to 2040 Versus Breakeven Oil Price

Sources: IEA, IPCC, Rystad UCube, Oil Change International analysis

What is the problem?

The problem is that the IEA did not update its climate scenario to reflect the 2015 Paris Agreement and the latest science.

When it first published its '450 Scenario' (450S) in 2008, the IEA was ahead of the curve. That scenario – designed to give a 50% probability of keeping warming to 2°C above pre-industrial levels – reflected the goals of many governments at the time.

Over the last decade, climate science has indicated that a 2°C warming poses more serious risks than previously thought. This was reflected in the IPCC's *Fifth Assessment Report* in 2013/14 and further confirmed in the IPCC *Special Report* of October 2018.[9]

It was for this reason that governments decided in 2015 to increase their ambition, committing in Paris to pursue efforts to limit warming to 1.5°C, and in any case to hold warming well below 2°C. The expert review that led to the Paris goals described 2°C as "an upper limit, a defence line that needs to be stringently defended, while less warming would be preferable."[10] In other words, decisions should be made so as to secure a very high probability (higher than 50% or 66%) of keeping warming below that threshold.

In the 2016 edition of the *World Energy Outlook (WEO)*, the IEA acknowledged that the 450S was not aligned with the Paris goals. However, when the IEA replaced the 450S with the new SDS in *WEO 2017* (the SDS added goals on air pollution and energy access), it kept the emissions profile the same as the 450S.

What is the solution?

The IEA should update the SDS in the manner it proposed in 2016, publishing two scenarios: one for 2°C (with high probability), and one for 1.5°C, both with a precautionary approach to assumptions on future 'negative emissions'. Following the Paris goals then would mean preferring decisions that align as closely as possible with the 1.5°C scenario and stay as far as possible below the 2°C scenario. Investment risks could be judged accordingly.

The IEA proposed this solution in the 2016 *WEO* and provided a brief sketch of two new scenarios, respectively giving a 66% probability of keeping below 2°C and a 50% probability of 1.5°C. The German government commissioned and funded a full exposition of the 66%-2°C Scenario, published in a standalone report in March 2017.[11]

However, when the IEA introduced the new SDS in November 2017, it reverted to the 450S emissions profile, rather than that of the scenarios reflecting the Paris goals, as shown in Figure 2.

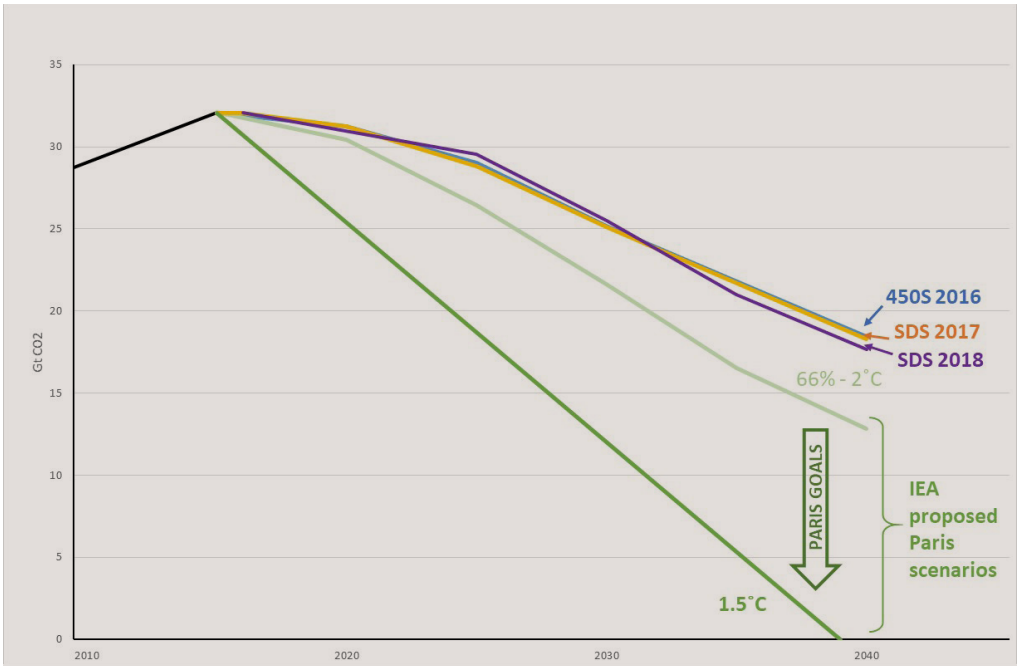

Figure 2: Carbon dioxide emissions from energy: comparison of IEA scenarios12

Source: IEA

What is a reasonable level of climate risk?

Scenarios with only a 50% or 66% probability of keeping warming below 2°C cannot (on their own) be seen as "safe climate" guides for energy decisions. The IEA was right in 2016 to propose publishing two scenarios to reflect the Paris goals, where decision makers should aim for the 1.5°C scenario and keep well below the 2°C scenario.

The greater the warming, the greater the impacts. Since scientific knowledge is finite, and the earth system immensely complex, much climate knowledge is couched in terms of probability and risk. Investors are used to dealing with uncertainties and managing risks: indeed, that is a large part of their job.

Warming of 2°C is now seen as very dangerous. An August 2018 paper in the *Proceedings of the National Academies of Science* warned that warming of 2°C could tip the earth into a new unstable 'hothouse' state, where cascading planetary feedback systems kept temperatures spiralling upwards, even if humanity stopped polluting.[13] It follows that we should expect a high confidence of keeping warming below that level.

For historical reasons, IPCC findings tend to be given for probabilities of >50% and >66%. The old 450 Scenario adopted the 50% probability of meeting 2°C because it meant (as a median) that it was as likely the outcome would be higher as that it would be lower, reflecting the 2008 ambition of aiming for 2°C.

With 2°C now seen no longer as a target, but as an absolute maximum tolerable level (where less warming is preferable), this reopens the question of the appropriate probabilities to use. The IEA has interpreted "well below 2°C" as having a 66% probability of keeping warming below 2°C.[14] Others argue that we need a much higher confidence of avoiding the dangers that scientists tell us could occur at and above 2°C. The UN Environment Programme's annual *Emissions Gap Report*, for example, uses 66% probability for each temperature target (including for 2°C prior to the Paris goals and for 1.8°C and 1.5°C more recently).[15] This implies that "pursuing efforts" for 1.5°C implies a 66% probability of success. By extension, the 66% probability of 2°C cannot be treated as a goal or target, but at best an upper boundary to aim "well below".

Why does the IEA say the SDS is aligned with the Paris goals?

The IEA claims the SDS is aligned with the Paris goals, based first on a misreading of the Paris Agreement, and second on an assumption that greater reductions will happen after the scenario ends in 2040, including through 'negative emissions'.

To recap: the IEA acknowledged in 2016 that the 450 Scenario was not aligned with the Paris goals. Yet today it claims that the SDS, which has the same emissions as the 450 Scenario, is "fully aligned" with the goals.[16] How can the same emissions lead to a different warming outcome? The reason is that the IEA has changed its assumptions for interpreting the scenario (rather than updating the scenario itself).

The IEA now makes two arguments that the SDS is aligned with the Paris goals. First, the IEA states that the SDS is aligned with the Paris goals because emissions in the SDS peak soon and then decline.[17] This however conflates the *goals* of the Paris Agreement[18] with its *mechanisms*. The goals, in Article 2.1 of the Agreement, are to hold warming well below 2°C and pursue efforts to limit warming to 1.5°C. The mechanisms, in Article 4.1, include to peak emissions soon and decline to net zero in the second half of the century. Many scenarios that satisfy those aspects of the mechanisms will not lead to achieving the goals: they are a necessary but not sufficient condition.

Second, the IEA observes that the climate outcome will be affected by emissions over the whole century (and beyond), whereas its scenarios run only to 2040.[19] So it is *theoretically* possible that after following the SDS until 2040, very rapid subsequent cuts in emissions and deployment of negative emissions technologies (NETs) could bring the world back within Paris-goals limits. The SDS does not itself lead to achievement of the Paris goals, but relies on a hope that later actions (not part of the scenario) will compensate for its inadequacy.

The IEA states that the SDS (in *WEO 2018*) has emissions "lower than most" IPCC scenarios that lead to 1.7 to 1.8°C outcomes (with 50% probability).[20] This is equivalent to aiming for

a 66% probability of keeping warming below 2°C, which is how the IPCC classifies that same scenario set.[21] Such scenarios cannot in themselves be seen as reflecting the Paris goals, as the 66% probability does not constitute "stringent defence" of the 2°C limit; at best they define the boundary that decisions need to aim "well below". In order to achieve the goals, emissions need to be lower than this - a reason a 1.5°C scenario is also needed. The IEA also says that the SDS is "within the envelope of scenarios projecting a temperature rise below 1.5°C."[22]

What do IPCC scenarios say?

The IEA's claims that the SDS is "lower than most" scenarios leading to 1.7 to 1.8°C, and "within the envelope" of 1.5°C scenarios, are only true if the comparison includes scenarios that assume extensive deployment of negative emissions technologies (NETs), at levels that are considered unrealistic in both IEA and IPCC assessments.

In *WEO 2016*, the IEA warned that large-scale deployment of bioenergy with carbon capture and storage (BECCS), as assumed in many models, "is vastly removed from the realities of the current energy system, and the prospect is remote from today's perspective."[23] Nonetheless, the IEA relies on that remote prospect to claim the SDS is aligned with the Paris goals.

In this section we revisit the IEA's comparison with IPCC scenarios,[24] but excluding the ones that rely on potentially unrealistic levels of NETs deployment. Specifically, we exclude any that have 2050 levels of BECCS, afforestation/reforestation or soil capture greater than the midpoint of the IPCC's estimated range of the methods' potential, which comes from recent literature assessing practical constraints.[25] This reduces the numbers of scenarios significantly, to 23 below-2°C scenarios (with 66% or higher probability), including seven 1.5°C scenarios (with low or no overshoot).[26]

Figure 3 compares emissions under the SDS with these seven 1.5°C IPCC scenarios: it shows that the SDS is a long way off course from all realistic 1.5°C scenarios (in contrast to the IEA claim to be "within the envelope" of 1.5°C when unrealistic scenarios are included).

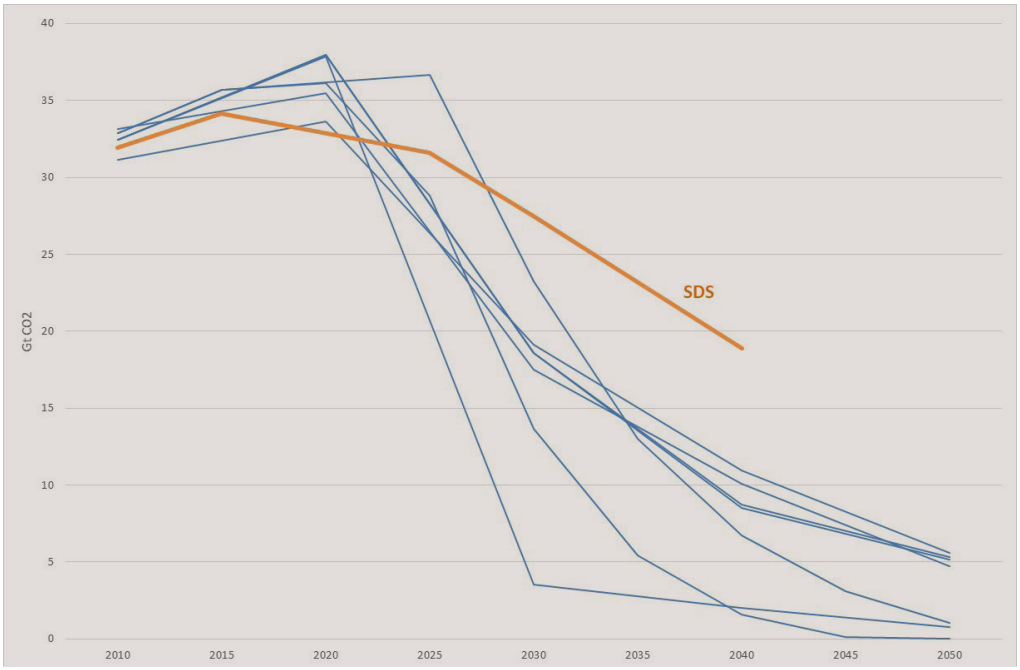

Figure 3: Carbon dioxide emissions (energy and industrial processes): SDS vs IPCC 1.5°C scenarios with BECCS < 2.75 Gt CO2 and AR < 2.05 Gt CO2 in 2050

Sources: IEA, IPCC/ IAMC 1.5°C Scenario Explorer and Data hosted by IIASA

Figure 4 compares the SDS with IPCC 2°C scenarios with realistic NETs assumptions. It shows that the SDS is towards the upper end of the range of these scenarios (in contrast to the IEA's claim to be "lower than most" when unrealistic scenarios are included). Recall that according to the Paris goals, these scenarios set the upper limit that emissions must stay below, not a target to aim for.

What is the status of negative emissions technologies (NETs)?

There is increasing concern in the scientific community over models' major reliance on NETs and the challenges of large-scale deployment of NETs are profound.[27]

For almost a decade many climate models have relied on an assumption that NETs will be available later in the century to suck excess carbon dioxide back out of the atmosphere. These technologies work very well in the models – they suit the models' cost-optimising logic – but to date some technologies have never been practiced at the scale required, and some not at all.[28] The recent IPCC report stated, "Carbon cycle and climate system understanding is still limited about the effectiveness of net negative emissions to reduce temperatures after they peak,"[29] adding that carbon dioxide removal "deployed at scale is unproven and reliance on such technology is a major risk in the ability to limit warming to 1.5°C."[30]

Bioenergy grown on the wrong soils, or replacing existing biomass, or using the wrong inputs (such as fertiliser and machinery) can emit more carbon dioxide (CO_2) than it absorbs.[31] CO_2 injected in the wrong geological structure may not be safe over the long term. Thus, to have an effective large-scale NETs system based on BECCS would require extensive monitoring and regulation, both of bioenergy growing and of carbon capture and storage (CCS), in order to ensure emissions were actually negative.[32] How this could be governed internationally, with what incentives, funding and penalties, is one of the largest uncertainties in the assumption that large-scale NETs will be available.[33]

Furthermore, most NETs will have significant environmental and social impacts. To give an idea of scale, using BECCS to remove 12 billion tonnes a year of CO_2 from the atmosphere – the median of 2°C scenarios in integrated assessment models – is estimated to require bioenergy grown on a land area 1 to 2 times the size of India, or 25 to 46% of total world crop-growing area.[34] This will necessarily have an impact on agriculture (and hence global food security) and/or biodiversity. Afforestation has a greater land intensity than BECCS.

That is not to say that efforts should not be made to develop BECCS and other NETs: they should. Rather, it is that decisions about the future of energy

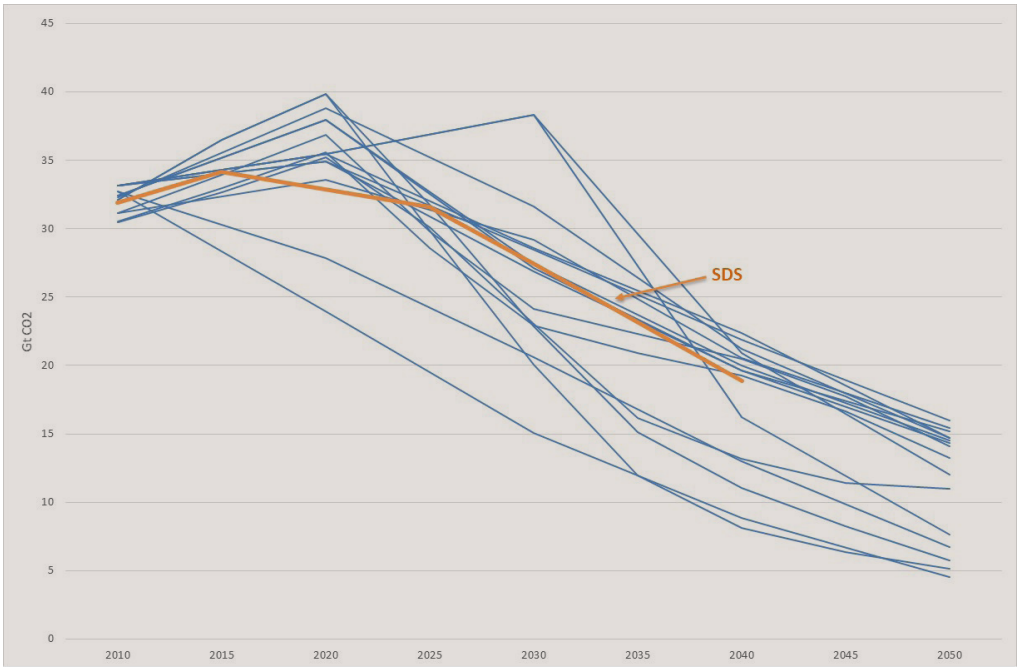

Figure 4: Carbon dioxide emissions (energy and industrial processes): SDS vs IPCC 2°C scenarios with BECCS < 2.75 Gt CO2 and AR < 2.05 Gt CO2 in 2050

Sources: IEA, IPCC/ IAMC 1.5°C Scenario Explorer and Data hosted by IIASA

– particularly fossil fuels – should not rely on an assumption that these technologies will overcome their challenges and be available at large scale.

Until *WEO 2016*, the IEA took a welcome precautionary approach to NETs: the 450 Scenario and two Paris-goal scenarios were designed to indicate what would be needed if such technologies (other than reforestation) did not become available.[35] The subsequent *WEO* warned that "all such technologies face severe technical, economic and resource constraints." And in its Tracking Clean Energy Progress report in June 2018, the IEA observed that the world is "far off track" from achieving progress in CCS,[36] which is a vital stepping stone towards NETs. Yet as shown above, the IEA's claims about the alignment of the SDS with the Paris goals depend on a very high deployment of NETs.

What changes with the new WEO 2018?

In WEO 2018, the IEA stepped away from the Paris goals, compared to the previous two editions of the WEO. It dropped both its Faster Transition Scenario and references to the 1.5°C goal.37

Whereas *WEO 2016* and *2017* discussed options for keeping warming to 1.5°C, *WEO 2018* does not, despite being published just one month after the IPCC Special Report highlighted both the critical importance of limiting warming to 1.5°C, and pathways for doing so. Furthermore, whereas *WEO 2016* sketched a 66%-2°C scenario and a 1.5°C scenario (both assuming no BECCS) and *WEO 2017* sketched the 66%-2°C scenario, *WEO 2018* disappointingly includes neither of those scenarios. Having dropped these scenarios, the *WEO 2018* instead claims the unchanged SDS is now "fully aligned" with 66% probability of 2°C.[38]

As Figure 1 above shows, emissions under the SDS are very slightly changed in *WEO 2018*. Primarily this is about delaying climate mitigation: emissions are slightly higher in the 2020s and slightly lower in 2040, compared to *WEO 2017*. However, the cumulative climate impact is the same.

What can investors do?

The IEA is now prioritising engagement with investors, as a key user group of its *WEO*. We recommend that:

Investors should individually and collectively engage the IEA to express their scenario needs. In particular:

- **The SDS should be updated to reflect the Paris goals, with scenarios reflecting both 1.5°C and a 66% probability of 2°C, as the IEA proposed in *WEO 2016*.**

- **The scenarios should revert to the IEA's previous precautionary assumption, that 'negative emissions' technologies may not become available at large scale.**

The IEA has a significant opportunity for leadership, an opportunity that it regrettably missed in WEO 2018. It would be easy for the IEA to update the SDS to match the Paris goals, in the manner the IEA itself proposed in 2016.

What other information can investors use for assessing investments?

We recommend that investors stress-test portfolios against multiple futures, including more than one future in which dangerous climate change is averted. However, the IEA has an important role to play as a common benchmark and as an accessible, user-friendly source of information, so its reform is important. In the meantime, there are other information sources investors can use.

Reliance on a single scenario – especially one that is not aligned with the Paris goals – would leave investors potentially exposed to unmanaged risks. We suggest three information sources that can also be used in examining these risks:

- **IPCC scenarios are published online.**[39] **These can be filtered according to amount of warming, and various other assumptions including the amount of BECCS or land sequestration.**
- **A 1.5°C energy scenario has been published by Ecofys.**[40]
- **Other scenarios (not necessarily aligned with Paris goals) explore particular drivers rather than the full energy system. There are growing numbers of forecasts focused specifically on clean energy, such as from Bloomberg New Energy Finance**[41] **and from the International Renewable Energy Agency,**[42] **which give a fuller picture of the potential of disruptive technology in their markets.**

On the other hand, the IEA publishes scenarios with more energy-related detail than most other providers (such as breakdowns by region, by fuel and by demand sector), in a form that is accessible and decision-oriented. The IEA is recognised for its expertise and profile and therefore often serves as a benchmark for comparing investments, strategies and other scenarios.

For these reasons, it is important that the IEA provide scenarios aligned with the Paris goals, notwithstanding the availability of the information described above. This is why we recommend reform of the IEA, rather than (or in parallel to) simply switching to an alternative provider.

Is the Beyond 2 Degrees Scenario better?

In 2017, the IEA published two scenarios aiming for a 66% probability of keeping warming below 2°C (rather than the 50% probability of the 450 Scenario): the 66%-2C Scenario discussed earlier and the Beyond 2 Degrees Scenario (B2DS). They do not reflect the Paris goals of keeping warming well below 2°C and pursuing efforts for 1.5°C, but they do define the 2°C upper boundary with greater confidence than the SDS and give an alternative picture of somewhat faster change.

The B2DS was introduced in the 2017 edition of the usually-annual *Energy Technology Perspectives (ETP)* report.[43] It gave more data than the 66%-2C Scenario, albeit in a different format from the *WEO*. That report was not published in 2018; the next is expected in June 2019. While the 66%-2C Scenario has been dropped, it remains to be seen whether the B2DS will be continued, and how if so how it relates to the SDS, given that the IEA has now changed its interpretation to describe that as a 66% probability of 2°C (or equivalently, 50% of 1.7 to 1.8°C).

The *ETP* uses a different model from the *WEO*; whereas the difference between scenarios in the *WEO* is policy ambition, in *ETP* the difference is technological optimism. While this includes disruptive technologies such as renewable energy and electric vehicles, it also includes sustaining technologies such as carbon capture and storage and negative emissions technologies. As such it potentially understates downside risk for fossil fuels, if disruptive technologies advance quickly and sustaining technologies stall, as is currently the case.

What about physical risk from climate change?

While this briefing has focused on the IEA's climate scenarios, the IEA gives these only a secondary role. The focus of the WEO is on a business-as-usual scenario, and so this is used most in guiding energy decisions: it thus risks becoming a self-fulfilling prophecy.

Losing money on fossil fuel investments is not the only, or even the biggest threat to financial investors: they also face losses due to the impact of climate change itself, both to their investments in climate-vulnerable sectors such as food, property and insurance, and to the wider economy. For example, the US National Climate Assessment in November 2018 found that by the end of the century, some economic sectors could face losses due to climate change in the hundreds of billions of dollars.[44] While investors face risks from an energy transition, they face potentially larger risks from the absence of a transition. A 2015 study by the Economist Intelligence Unit, commissioned by Aviva Investors, estimated that $4.3 trillion of today's financial assets are at risk from climate change. [45]

The IEA has a role to play here too. The vast majority of the *WEO* is focused on the 'New Policies Scenario' (NPS), which would lead to around 3°C of warming.[46] By comparison, the SDS gets only one paragraph in the six-page summary of *WEO 2018*. Since the NPS is so centrally communicated by the IEA, it is the NPS that energy decision makers use as the default guide. With the resulting lock-in of emissions by infrastructure and policies, the NPS thus risks becoming a self-fulfilling prophecy.[47] For this reason, member governments, civil society and investors are calling for the IEA to make an updated SDS the centre of the *WEO*, in place of the NPS.

Where can I find out more?

Further resources are available from Oil Change International and Greenpeace UK:

Investor briefing: *Off Track: The IEA and Climate Change*: **priceofoil.org/2018/04/04/off-track-iea-briefing-for-investors/**

Report: *Off Track: The IEA and Climate Change:* (co-published with the Institute for Energy Economics and Financial Analysis): **priceofoil.org/iea-off-track/**

Commentary on *WEO 2018*: 'The IEA Comes Up Short on Climate (Again)': **priceofoil.org/2018/11/12/business-as-usual-iea-climate/**

Oil Change International and Greenpeace UK are ready to support investors in engaging with the IEA and help them coordinate with other advocates (such as member governments) engaging the IEA. Please contact:

Greg Muttitt, Oil Change International: **greg@priceofoil.org**

Charlie Kronick, Greenpeace UK: **charlie.kronick@greenpeace.org**, +44 7801 212 963

Louise Rouse: **louise@louiserouse.org**, +44 7751 256 163

This briefing was researched and written by Greg Muttitt, with contributions from Kelly Trout, Charlie Kronick and Louise Rouse. The author is grateful for feedback from the following reviewers: Kaisa Kosonen, Denise Puca, Hannah McKinnon, Bert Metz, Glen Peters and Helen Wildsmith. Any errors remain the responsibility of the author.

Design by Keith Dodds

Published by Oil Change International and Greenpeace UK.

Oil Change International is a research, communications, and advocacy organization focused on exposing the true costs of fossil fuels and facilitating the coming transition towards clean energy. www.priceofoil.org

Greenpeace is an independent organisation campaigning to ensure a peaceful and sustainable world for future generations. **www.greenpeace.org**

Endnotes

1 References
Available at https://www.iea.org/weo2018/

2 http://www.climateaction100.org/

3 Task Force on Climate-related Financial Disclosures (TCFD), Recommendations, 14 December 2016, https://www.fsb-tcfd.org/wp-content/uploads/2016/12/16_1221_TCFD_Report_Letter.pdf

4 (or in some cases the predecessor 450 Scenario, which has the same emissions as the SDS, as discussed below.) See Greg Muttitt, Off Track, Oil Change International and Institute for Energy Economics and Financial Analysis report, April 2018, p.28 http://priceofoil.org/iea-off-track/

5 Muttitt, Off Track, op.cit.4, pp.30-32
See also accompanying investor briefing, Off Track, co-published by Oil Change International and Greenpeace UK, http://priceofoil.org/2018/04/04/off-track-iea-briefing-for-investors/

6 We treat oil and liquified natural gas (LNG) each as trading in a single global market and divide dry gas into five regional markets.

7 We assume that those budgets are shared between oil, coal and various regional gas markets in the same proportions (by emissions) as in the IEA's Beyond 2 Degrees Scenario. We further assume that 70% of the 2°C budget is used by 2040, and 100% of the 1.5°C budget. We make optimistic assumptions on non-energy emissions, totalling 180 Gt of CO2 between 2016 and 2100.
Note that this analysis was done using carbon budgets from the IPCC's Fifth Assessment Report (AR5). The IPCC's Special Report on Global Warming of 1.5 Degrees (SR15) subsequently revised carbon budget estimates upward, such that the new 1.5°C budget is similar to the AR5 2°C budget. The important thing here is not the precise numbers but the general finding: the investment called for in the SDS considerably exceeds the amount that would be aligned with the Paris goals.

8 For full methodology and assumptions, see Muttitt, Off Track, op.cit.4, pp.30-32

9 IPCC, SR15, op.cit.7, p. 9-13, http://www.ipcc.ch/pdf/special-reports/sr15/.

10 UNFCCC Subsidiary Body for Scientific and Technological Advice, 42nd Session, Bonn, 1–11 June 2015, Report on the Structured Expert Dialogue on the 2013–2015 Review, p.18, http://unfccc.int/resource/docs/2015/sb/eng/inf01.pdf

11 IEA and IRENA, Perspectives for the Energy Transition, March 2017, http://www.irena.org/publications/2017/Mar/Perspectives-for-the-energy-transition-Investment-needs-for-a-low-carbon-energy-system
This is one of two IEA scenarios with a 66% probability of keeping below 2°C; the other – the Beyond 2 Degrees Scenario – is discussed below on page XX

12 450, 66% - 2°C, 1.5°C scenarios: IEA, World Energy Outlook (WEO) 2016, pp.339, 345, 553. Note although WEO 2016 focused on no-BECCS scenarios, it also showed emissions for 1.5C scenarios with varying levels of BECCS, which would enable higher emissions during the scenario period.
SDS 2017: IEA, WEO 2017, p.651.
SDS 2018: IEA, WEO 2018, p.529.

13 Will Steffen et al, "Trajectories of the Earth System in the Anthropocene," PNAS 115:33, 14 August 2018, pp. 8252–8259, www.pnas.org/cgi/doi/10.1073/pnas.1810141115

14 IEA, WEO 2016, p.338

15 UNEP, Emissions Gap Report 2014, pp.ix ff, https://www.unenvironment.org/resources/emissions-gap-report-2014; UNEP, Emissions Gap Report 2018, pp.xvii, xix, https://www.unenvironment.org/resources/emissions-gap-report-2018

16 IEA, WEO 2018, p.29

17 IEA, WEO 2018, p.84

18 UNFCCC, The Paris Agreement, https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

19 IEA, WEO 2017, p.134-5

20 IEA, WEO 2018, p.89

21 The IEA presumably describes them differently for communications reasons.

22 IEA, "World Energy Outlook 2018: Q&A", https://www.iea.org/weo2018/qa/

23 IEA, WEO 2016, p.338

24 IAMC 1.5°C Scenario Explorer hosted by IIASA, release 1.0, accessed 12 December 2018, http://data.ene.iiasa.ac.at/iamc-1.5c-explorer/
For 1.5°C, we use the scenarios categorised "below 1.5C" or "1.5C low overshoot", following the IPCC SR15 (op.cit.7), which focuses on scenarios with low or no overshoot, "recognizing the very different potential impacts and risks associated with high-overshoot pathways" (p.60). For 2°C, we use those categorised "1.5C high overshoot" or "lower 2C", the latter referring to scenarios that limit warming below 2°C with a probability of at least 66%.

25 The recent IPCC Special Report estimates that the potential to remove CO2 from the atmosphere by BECCS will be somewhere between 0.5 and 5 Gt of CO2 per year by 2050, and by afforestation/reforestation (AR) between 0.5 and 3.6 Gt (IPCC SR15, pp.342-3). These are uncertainty ranges for the potential (ie maximum possible, not actual): the potential may be as low as 0.5 Gt of each, or as high as 5 and 3.6 Gt respectively; we take the midpoint of the ranges to reflect the best available estimate. We exclude scenarios for which BECCS or AR exceed the midpoint of these ranges in 2050, or where combined soil carbon sequestration and biochar exceed 3.8 Gt. For scenarios that do not publish these data, we further exclude scenarios which have negative agriculture, forestry and other land use (AFOLU) emissions exceeding the sum of these midpoints, or where cumulative land sequestration from 2016 to 2100 exceed 50 times that sum. Future availability of further data may allow this approach to be refined: a weakness is that it treats the limits of different biomass-based NETs as additive rather than competing for land, and in the first case it ignores positive AFOLU emissions included in the total.

26 Out of respectively over 160 and over 50 scenarios. The striking fact that the majority of IPCC scenarios rely on unrealistic levels of NETs is a result of the structure of the models, discussed below.

27 For example, Kevin Anderson & Glen Peters, "The Trouble With Negative Emissions," Science 354:6309, 14 October 2016, pp.182-3, http://www.web.cemus.se/wp-content/uploads/2018/02/The-Trouble-with-Negative-Emissions.pdf

28 For example, the world's only operating BECCS plant, near Decatur, Illinois (USA), captures CO2 from the fermentation reaction in manufacturing ethanol from maize; it does not capture combustion emissions from subsequently burning the ethanol.

29 IPCC SR15, op.cit.7, p.19

30 IPCC SR15, p.96

31 IPCC SR15, pp.324-5; Clair Gough & Naomi Vaughan, "Synthesising Existing Knowledge on the Feasibility of BECCS," AVOID2 report, February 2015, pp.15, 24-5, http://avoid-net-uk.cc.ic.ac.uk/wp-content/uploads/delightful-downloads/2015/07/Synthesising-existing-knowledge-on-the-feasibility-of-BECCS-AVOID-2_WPD1a_v1.pdf; Mathilde Fajardy & Niall MacDowell, "Can BECCS Deliver Sustainable and Resource Efficient Negative Emissions?" Energy & Environmental Science 10, 2017, p.1391, https://spiral.imperial.ac.uk/bitstream/10044/1/47928/7/c7ee00465f.pdf

32 Gough & Vaughan, op.cit.27, p.18

33 IPCC SR15, p.343; Felix Creutzig, "Bioenergy and Climate Change Mitigation: An Assessment," GCB Bioenergy, 7(5), 2015, pp.916–944. https://doi.org/10.1111/gcbb.12205; Naomi E Vaughan and Claire Gough, "Expert assessment concludes negative emissions scenarios may not deliver," Environmental Research Letters 11, 2016, http://iopscience.iop.org/article/10.1088/1748-9326/11/9/095003/meta; Henry Shue, "Climate Dreaming: Negative Emissions, Risk Transfer, and Irreversibility," Journal of Human Rights and Environment 8, 2017, pp.203–16, https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2940987

34 IPCC SR15, p.343; Pete Smith et al, "Biophysical and Economic Limits to Negative CO2 Emissions," Nature Climate Change, 7 December 2015, p.5 https://doi.org/10.1038/NCLIMATE2870

35 IEA, World Energy Model Documentation, 2016 Version, p.49

36 IEA, "Tracking Clean Energy Progress: CCUS in Power," May 2018, https://www.iea.org/tcep/power/ccs/

37 Greg Muttitt, "The IEA Comes Up Short on Climate (Again)", 12 November 2018, http://priceofoil.org/2018/11/12/business-as-usual-iea-climate/

38 IEA, WEO 2018, p.29

39 http://data.ene.iiasa.ac.at/iamc-1.5c-explorer/

40 Ecofys, "Energy Transition Within 1.5°C: A Disruptive Approach to 100% Decarbonisation Of the Global Energy System by 2050," April 2008, https://www.ecofys.com/en/publications/energy-transition-within-15c/

41 Bloomberg New Energy Finance, New Energy Outlook 2018, https://about.bnef.com/new-energy-outlook/

42 IRENA, Global Energy Transformation: A Roadmap to 2050, April 2018, http://irena.org/publications/2018/Apr/Global-Energy-Transition-A-Roadmap-to-2050

43 Available at https://www.iea.org/etp/

44 U.S. Global Change Research Program, Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II, 2018, p.26, https://www.globalchange.gov/browse/reports/overview-fourth-national-climate-assessment-volume-ii-impacts-risks-and-adaptation

45 Economist Intelligence Unit, "The cost of inaction: Recognising the value at risk from climate change," 2015, p.2, https://www.aviva.com/content/dam/aviva-corporate/documents/socialpurpose/pdfs/thoughtleadership/EIU-cost-of-inaction.pdf

46 The IEA estimates that the NPS would set the world on course for 2.7 of warming (WEO 2017, p.117). See Muttitt, Off Track, op.cit.4, for a comparison with other scientific estimates.

47 Muttitt, Off Track, op.cit.4, pp.18-23