Annex E: Comparing mitigation investments in a bounded future

1. Tipping points and biophysical deadlines

In negotiations surrounding the Paris Agreement, most countries accepted that there would be severe consequences if mean global surface temperature rise were to exceed 1.5ºC, which was therefore subsequently adopted as the upper boundary of how much global heating could be allowed. The precise mechanism of what would happen if the temperature limit was breached remains unclear, but there is ample evidence for the involvement of ecological tipping points in Arctic, equatorial and oceanic systems[1]. The processes of ice-melt, fire, decay, acidification and oceanic heating in these cases are amplifying each other, and their trajectories are converging. Among the clearest processes to visualise is the decline in Arctic sea ice since 1979, which is leading towards an ice-free Arctic Ocean from the 2030s (Figure 1), driven by sustained heating well in excess of 1.5ºC (Figure 2).

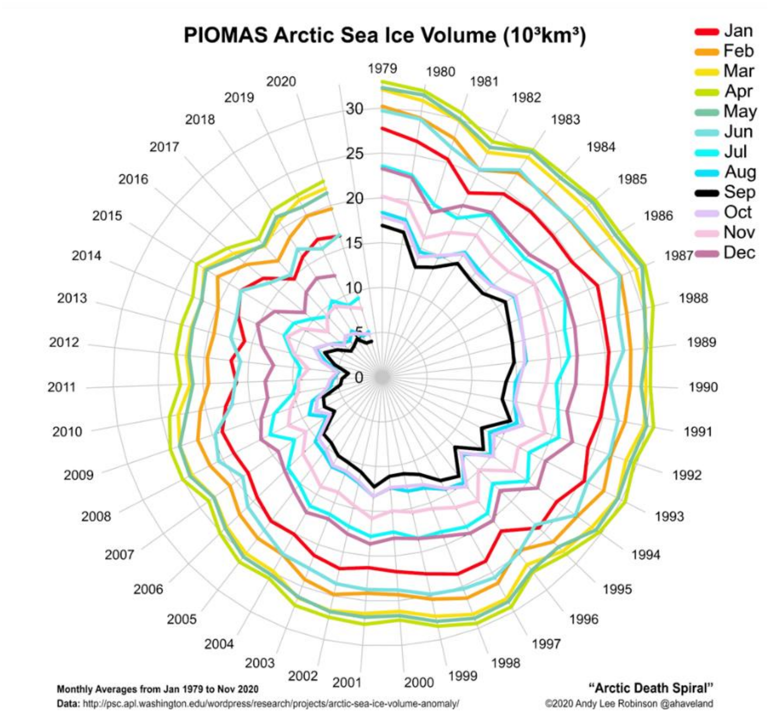

Figure 1: Decline in Arctic Ocean sea ice, January 1979-November 2020[2].

[1] This annex shares content with a parallel publication, *Surviving Climate Chaos by Strengthening Communities and Ecosystems*, © Julian Caldecott (Cambridge University Press, 2021).

[2] PIOMAS is the Pan-Arctic Ice Ocean Modelling and Assimilation System developed by the Polar Science Center at the University of Washington (PSC, 2020a, 2020b). The Arctic Sea Ice visualization is © Andy Lee Robinson, and is used with permission.

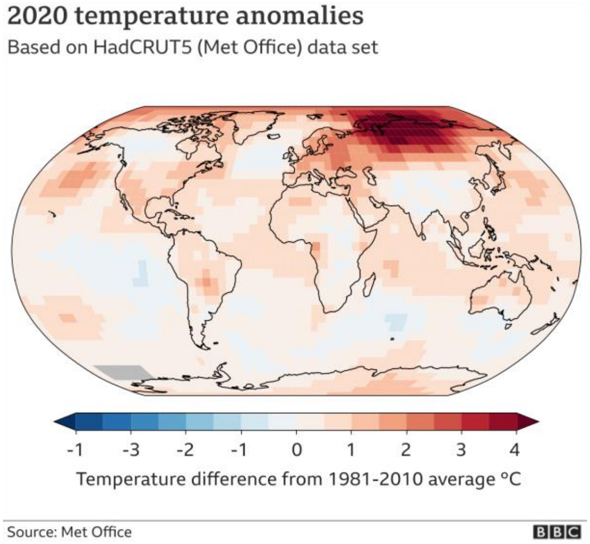

Figure 2: The melting Arctic, 2020[3].

The implication here is that much of the excess heat trapped on Earth by the greenhouse effect and not absorbed by the deep ocean (Figure 3) has so far been going into melting ice, but from the 2030s this will no longer be the case (Wadhams, 2016, 2017). The physics of ice, water and heat - specifically the 80-fold greater amount of heat energy required to melt ice than to heat water - would then be expected to induce accelerated heating of waters in and around the Arctic, permafrost melting, and the rapid release of potentially hundreds of gigatonnes (Gt) of methane (CH_4) from sea-beds and peat. This would quickly amplify the greenhouse effect to bring about environmental conditions very different to any that humanity has known.

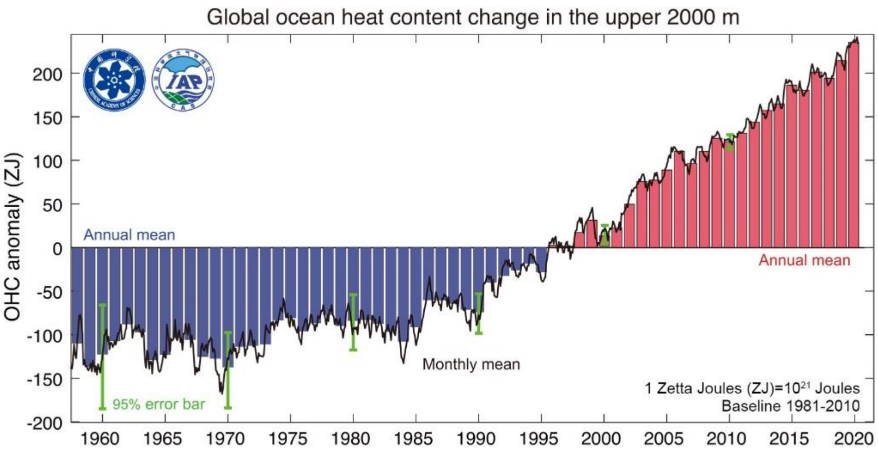

Figure 3: Changes in oceanic heat content, 1956-2020[4].

The key point is that the GHGs so far released, and continuing to be released at a rate of over 50 $GtCO_2e$/year, have been driving global heating in a roughly linear way, but that a dangerous non-linear response is now expected in mid-century (i.e. 2050 ± 10 years). Once that occurs, the biosphere would

[3] Source: © Met Office & BBC (https://www.bbc.co.uk/news/science-environment-55663544).

[4] Ocean heat is measured in zettajoules (ZJ), with 1.0 ZJ being equal to approximately double humanity's annual world energy use at present. Source: Cheng *et al.* (2021), © Springer).

likely continue to change according to its own feedback system, and human agency would effectively cease. From that point on, reducing net GHG emissions can make no significant difference to outcomes[5].

This is a scenario that is hard to accept emotionally and might be too pessimistic in terms of breakdown timing. It also might be too optimistic, since the final tipping points could already have been reached. Our knowledge of biosphere behaviour is rapidly increasing but is still very limited. With this uncertainty in mind, a precautionary attitude is necessary, and here a mid-century climate breakdown is assumed to be inevitable unless net GHG emissions are slashed dramatically and then reversed, starting immediately[6].

2. Target-consistent vs deadline-aware mitigation

Several countries, including the UK in 2008 and Denmark in 2019, have established legally-binding 2050 deadlines for reaching net zero GHG emissions. The EC is encouraging other countries to do the same, calling for net zero emissions by 2050 and a halving or more of emissions by 2030. Similar goals were also announced in late 2020 by China, Japan and South Korea, and the US followed suit in January 2021[7]. Deadlines that are legally binding require a 'target-consistent' approach. They use time-bound limits to replace the 'social cost of carbon' approach, and so are based on an estimate of what is needed for the limit to be complied with. This requires planners to work backwards from their legal deadline, setting carbon prices and other incentives and rules that are consistent with the time-bound emissions limit. To demonstrate any progress towards an emission limit requires the emission consequences of specified actions to be predicted (for planning) and measured (for compliance), and that these emissions must be specified net of all factors that might affect them.

3. Correcting tCO_2e to tCO_2edmv

Emissions can be compared in tCO_2e over very short time horizons. But to compare the effectiveness of alternative mitigation investments in the longer term it is necessary to take the approaching mid-century climate breakdown into account. This is because as biophysical returns on mitigation investments are delivered closer to the breakdown, they become less valuable in mitigation terms because the system itself is becoming more committed to breaking down[8].

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[5] A similar distinction can be made when someone chooses to walk to the edge of a high cliff and step off, since with the last step gravity takes over, and second thoughts become irrelevant.

[6] A climate breakdown is not a singular event with a fixed schedule, however. Rather the whole system is dynamic, with inertia, time-lags and tendencies to amplify and damp down changes, most of them poorly understood. So the aim of mitigation action now is not to cancel the breakdown but to postpone it, thus buying time to take other actions.

[7] Net zero targets refer to 'territorial' or 'production-based' emissions, and not 'consumption' emissions from the manufacture, growing and shipping of imported commodities. In 2017, Denmark had 35 $MtCO_2$ in territorial emissions but 53 $MtCO_2$ with consumption emissions added (https://ourworldindata.org/grapher/production-vs-consumption-co2-emissions?time=1990..latest&country=~DNK). According to MoE and VS interviewees, the 18 $MtCO_2$ difference was partly accounted for by imported soy and palm oil produced via tropical deforestation.

[8] Or so experience of positive system feedbacks and physical momentum suggests. There are examples of system behaviour where resistance to change increases under pressure (e.g. compressed snow resists melting, compressed armies resist invaders), but these seem irrelevant to the climate-biosphere system.

Assuming that emission savings are documented, a biophysical deadline can be factored into expected emission savings by correcting the mitigation value of each tCO_2e saved according to when it is saved. Rather than using tCO_2e to measure mitigation effectiveness, therefore, this would mean using annual tCO_2edmv, where 'dmv' stands for 'dated mitigation value'.

The expected mitigation effects of an investment would then be expressed, for example, as $tCO_2edmv2025$ which is worth more than $tCO_2edmv2030$, etc. Correcting tCO_2e to tCO_2edmv can be done by multiplying the net tCO_2e saving expected in each year by a factor that declines exponentially from 1 in the starting year to almost zero 30 years later, to yield a dmv for each. Thus, for example, if 2020 is the year from which the mitigation effects of an investment are counted, then 1.00 $tCO_2edmv2020$ would become 0.37 $tCO_2edmv2030$, 0.14 $tCO_2edmv2040$, and 0.05 $tCO_2edmv2050$ (Table 1).

Table 1: Exponential decay in dated mitigation value for correcting tCO2e to tCO2edmv.

Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Exp.	1.00	0.90	0.82	0.74	0.67	0.61	0.55	0.50	0.45	0.41	0.37	0.33	0.30	0.27	0.25	0.22
Year	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
Exp.	0.20	0.18	0.17	0.15	0.14	0.12	0.11	0.10	0.09	0.08	0.07	0.07	0.06	0.06	0.05	0.05

4. Steps in comparing investments

This offers greater clarity in comparing real mitigation usefulness between early emission gains from fast-acting investments versus later ones from slow-acting ones. It would fit into the middle of a three-step process to compare proposed mitigation projects realistically:

- **Step 1 is to estimate the net physical emission savings** expected in each year (in tCO_2e), after taking account of all increased emissions from construction, transport, operation and indirect social and economic effects of the investment. This will highlight actions that deliver powerful results early relative to those that deliver weak results late.
- **Step 2 is to correct the annual physical tCO_2e savings** according to when they occur and adding all the dated mitigation values to yield a total mitigation value (ΣtCO_2edmv) over a standard period, say 20 years[9]. This will amplify highlighting from Step 1, while adding a sense of urgency and comparability among portfolios.
- **Step 3 is to add the value of co-benefits in each case**, using proxies and policy preferences to list and weight all those considered important, including adaptation, water, biodiversity, local cultural and amenity values, and contributions to the SDGs. This will additionally highlight actions that yield abundant co-benefits for many sectors or interests, relative to those that benefit only one or a few of them.

5. A comparison of three investment models

Table 2 illustrates the effect of applying Steps 1 and 2 to three model cases.

[9] It could also be useful to divide the ΣtCO_2edmv by total investment cost (Σ€) over the period to yield a mitigation benefit per unit cost (tCO_2edmv/€), which could be compared with the tCO_2edmv/€ of other potential investments over the same period. This would require more complex financial and economic modelling than is attempted here.

- The first case ('Avoided Deforestation' in Table 2a) is modelled on the Harapan project in Sumatra, whereas described in Annex I large areas of intact and damaged forest were set aside within an Ecosystem Restoration Concession (ERC) and managed by local communities in partnership with the ERC concession holders and the BirdLife family of NGOs. Resulting emission savings are estimated based on data in Annex D on ecological mitigation.
- The second case ('Renewable Energy' in Table 2b) is modelled on the Assela Wind Farm Project (AWFP) in Ethiopia, as described in Annex H and using data on costs, emission savings and the grant component from the project document and elsewhere[10].
- The third case ('Capacity Building' in Table 2c) is much more speculative than the others, being merely inspired by capacity-building partnerships between Danish and developing country institutions, including dialogue and advice on policy and regulation in the energy sector as the partner country is encouraged and enabled to solve problems of incentivising RE investment and integrating increased RE generation into its national grid. If this kind of collaboration is to be justified as a use of mitigation funding, then some impact on emissions must at least be hoped for at some point in the future. A small impact is assumed in order to illustrate its effect, using South African emissions (Annex J) as an example, with other assumptions given in the notes to the table.

[10] The minutes of the Council for Development Policy (12 April 2018) record that the: "DBF [Danida Business Finance grant] would cover all interest and expenses of the loan as well as give a 'cash grant', which would bring the total subsidy to 50 [percent]. of the contract sum." Thus the subsidy element doubled the investment available.

Table 2: Model mitigation investments with different cost-effectiveness and short- and medium/long-term effects.

(1) Year	(2) Investment (EUR)	(3) Physical tCO_2e saved	(4) Exponential decline in mitigation value factor (Table 1)	(5) Mitigation value of tCO_2e saved in that year (3 x 4 = n tCO_2edmv)
Table 2 (a): 'Avoided Deforestation': Harapan model (Annex I).				
2020	3,000,000	10,000,000	1.00	10,000,000
2021	3,000,000	175,000	0.90	158,347
2022	3,000,000	175,000	0.82	143,278
2023	3,000,000	175,000	0.74	129,643
2024	3,000,000	175,000	0.67	117,306
2025	3,000,000	175,000	0.61	106,143
2026	3,000,000	175,000	0.55	96,042
2027	200,000	175,000	0.50	86,902
2028	200,000	175,000	0.45	78,633
2029	200,000	175,000	0.41	71,150
2030	200,000	175,000	0.37	64,379
2031	200,000	175,000	0.33	58,252
2032	200,000	175,000	0.30	52,709
2033	200,000	175,000	0.27	47,693
2034	200,000	175,000	0.25	43,154
2035	200,000	175,000	0.22	39,048
2036	200,000	175,000	0.20	35,332
2037	200,000	175,000	0.18	31,970
2038	200,000	175,000	0.17	28,927
2039	200,000	175,000	0.15	26,175
2040	200,000	175,000	0.14	23,684
2020-2040	**23,800,000**	**13,500,000**	**-**	**11,438,767**
Table 2 (b): 'Renewable Energy': Assela Wind Farm model (Annex H).				
2020	50,100,000	0	1.00	0
2021	50,200,000	43,750	0.90	39,587
2022	50,300,000	87,500	0.82	71,639
2023	50,400,000	131,250	0.74	97,232
2024	400,000	175,000	0.67	117,306
2025	400,000	175,000	0.61	106,143
2026	400,000	175,000	0.55	96,042
2027	400,000	175,000	0.50	86,902
2028	400,000	175,000	0.45	78,633

2029	400,000	175,000	0.41	71,150
2030	400,000	175,000	0.37	64,379
2031	400,000	175,000	0.33	58,252
2032	400,000	175,000	0.30	52,709
2033	400,000	175,000	0.27	47,693
2034	400,000	175,000	0.25	43,154
2035	400,000	175,000	0.22	39,048
2036	400,000	175,000	0.20	35,332
2037	400,000	175,000	0.18	31,970
2038	400,000	175,000	0.17	28,927
2039	400,000	175,000	0.15	26,175
2040	400,000	175,000	0.14	23,684
2020-2040	**207,800,000**	**3,237,500**	**-**	**1,215,957**
Table 2 (c): 'Capacity Building': South Africa policy and regulation model (Annex J & note).				
2020	1,000,000	0	1.00	0
2021	1,000,000	0	0.90	0
2022	1,000,000	0	0.82	0
2023	1,000,000	0	0.74	0
2024	1,000,000	0	0.67	0
2025	0	500,000	0.61	303,265
2026	0	500,000	0.55	274,406
2027	0	500,000	0.50	248,293
2028	0	500,000	0.45	224,664
2029	0	500,000	0.41	203,285
2030	0	1,000,000	0.37	367,879
2031	0	1,000,000	0.33	332,871
2032	0	1,000,000	0.30	301,194
2033	0	1,000,000	0.27	272,532
2034	0	1,000,000	0.25	246,597
2035	0	1,500,000	0.22	334,695
2036	0	1,500,000	0.20	302,845
2037	0	1,500,000	0.18	274,025
2038	0	1,500,000	0.17	247,948
2039	0	1,500,000	0.15	224,353
2040	0	1,500,000	0.14	203,003
2020-2040	**5,000,000**	**16,000,000**	**-**	**4,361,855**

Assumptions in the 'Capacity Building' model:

- Advisers work over five years with partner ministries to encourage and enable improvements in the policy and regulatory system and build capacity to manage the promotion of economy-wide decarbonisation investment in partnership with private investors and communities. The effectiveness (impact, sustainability) and attributability of these efforts are likely to be very uncertain.
- Physical emissions savings are zero for the first five years because it takes time for studies, stakeholder dialogue and training to be done, forums to be set up, trust to be built, and for policies and legislation to be developed and become established in law and practice.
- From year 6, total national emissions of 500 Mt CO_2e [in the South African example] are reduced by 0.1% (0.5 million tonnes)/year, attributable to the impact of the capacity-building investment.
- From year 11, and again from year 16, the share of reduced emissions attributable to the capacity-building investment increases due to multiplier effects (such as from lesson learning, amendment of legislation, an increase in experienced staff). Rather than a series of step changes, this could be modelled as an exponential increase in economy-wide capacity to deliver emission reductions over time.

In Table 2(a), the Harapan project relies for most of its mitigation effectiveness on the 10 MtCO_2e savings that are accounted in year one of a seven year community-based forest conservation project[11]. Thereafter there is an accretion of carbon in the growing forest[12], sustained by maintaining the community-forest system. Here a public investment of EUR 28.8 million yields 11.4 MtCO_2edmv over 21 years (or 0.4 tCO_2edmv/EUR).

In Table 2(b), the AWFP saves no emissions at first, but does so over time in a predictable way due to the substitution of wind-generated electricity for electricity generated by burning fossil fuels, sustained by maintenance of the wind turbines. Here a public grant of about EUR 100 million (DKK 727.3 million) leverages a total of EUR 208 million invested, which yields a saving of 1.2 MtCO_2edmv over 21 years (or 0.01 tCO_2edmv/EUR).

In Table 2(c), capacity building also saves no emissions at first, but does so over time as the government responds to increased awareness of options and takes advantage of the TA and policy guidance deployed through the partnership. The effects are unpredictable in detail but should have been anticipated in making the case for investing in each specific partnership. Here they are represented by a small increase in the renewables contribution to the national energy supply, with an investment of EUR 5.0 million yielding 4.4 MtCO_2edmv over 21 years (or 0.9 tCO_2edmv/EUR).

The key point from Table 2(c) is that very large reductions in physical GHG emissions are possible with small investments, because of the economy-wide effects of policy and regulatory change over time, but that these returns are slow in coming so their mitigation value is reduced relative to investments that deliver quicker results. Nevertheless, public 'capacity building' investments are cheap and seem valid from this model on cost-effectiveness grounds. They are certainly key to transforming national energy sectors in the medium to long term, assuming adequate (largely private) investment in RE and EE. Refinement of the Table 2(c) model would therefore be particularly useful as a way to justify this kind of investment strategy.

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[11] The 'avoided deforestation' actually becomes real over time, as the project changes local attitudes and priorities. The assumed 10 MtCO_2e is at the lower end of the estimated range of 10-15 MtCO_2e for Harapan.

[12] Forest regrowth is vividly illustrated by maps of ecosystem recovery between 2006 and 2018 for a similar project in Mbeliling, also in Indonesia (see Annex I; for rates of carbon absorption by growing forests see Annex D).

Looking just at the two models with relatively certain costs and mitigation benefits, however, it can be seen that without correcting the expected emission reductions for delivery date, there is a four-fold difference in tCO_2e savings between the two models, but with the correction this becomes a ten-fold difference. This illustrates the amplifying effect of correcting tCO_2e to tCO_2edmv, which would be important in decision making where tCO_2e profiles are similar, but is far more important when comparing cost-effectiveness, because of the multiplication involved. Thus, Table 2(a) and (b) suggest that these two investments offer roughly a ten-fold difference in mitigation value and a four-fold difference in cost to the tax-payer, or a 40-fold difference in overall cost-effectiveness. Considering only their relative contributions to postponing mid-century climate breakdown, on the assumptions used here it is clear that a Harapan-like project would have much the stronger case for mitigation financing.

Other factors should also be considered, however, notably:

- that **different co-benefits** are involved – for Harapan they reside in local biophysical effects (biodiversity, environmental services and security, etc.), but for AWFP (and 'capacity building' more generally) they take the form of development gains from increased RE supply and political economy effects (diplomacy, employment, equity, etc.), and these cannot be compared directly;
- that a **complete mitigation strategy** should include a variety of investments with a range of mitigation effect profiles, since immediate GHG savings are valuable in the short-term (i.e. to postpone climate breakdown), but strategic decarbonisation is also needed in the longer term (i.e. to postpone it further, and to prevent a recurrence);
- that **large and immediate emission reductions** are needed to off-set the emission deficits to be expected of countries capping their territorial but not their consumption emissions, and also to off-set the increasing emissions of countries that do not intend or are unable to cap their own emissions; and
- that **even temporary success**[13] in preventing emissions is worth seeking, since this will buy time either to make the measures permanent or to find ways to off-set or re-capture the emissions that will eventually occur, and meanwhile every tCO_2e not released is subtracting every year from its overall heat-trapping effects.

A 40-fold difference in cost-effectiveness between investment strategies in one of their shared goals is worthy of policy attention. Fuller analyses of financial and co-benefit consequences are needed, but the implications of this preliminary study are significant. If a tipping point-driven, mid-century climate breakdown and the need to use dated mitigation values are accepted, then:

- first, it would need to be factored consistently into Denmark's entire programme of mitigation investments in developing countries, across *all* institutional actors; and
- second, for the purposes of planning, monitoring and reporting humanity's mitigation efforts in a consistent way at a global level, every country and every mitigation investor and investment

[13] i.e. deforestation deferred rather than avoided; in the Harapan case, a proposed new road now threatens to undo some of the gains since 2002 when the BirdLife Consortium first became involved in the area (see map in Annex I).

would need to use the *same* dated starting point and the *same* exponential dmv decay factor for calculating, correcting and comparing the effects of their investments.

These points are as applicable to Denmark as to any other country with ambitions to mount an effective climate response. The first can be addressed through rationalisation of the whole long-term mitigation strategy, which in Denmark is already underway. The second point requires intergovernmental consensus and a UNFCCC response, so could be sought through UNFCCC channels, for example by being tabled and discussed at CoP 26/2021 in Glasgow and decided upon at subsequent meetings.

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