EXPONENTIAL CLIMATE ACTION ROADMAP 1.0

Assumptions and Methodology

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Erik Pihl and Avit Bhowmik, Future Earth

Jens Malmodin, Ericsson

www.futureearth.org

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INTRODUCTION

The Exponential Climate Action Roadmap presents sets of solutions that could potentially halve emissions sector by sector, to achieve the overall goal of halved global carbon dioxide equivalent (CO_{2e}) emissions every decade to 2050, with focus on the "first halving" to 2030. Trajectories for emissions reductions have been assessed through backcasting, using current emissions as baseline and assessing what trajectories that give a 50% reduction per sector. Baselines are determined for each sector with a model that is set up to strictly avoid double-counting of emissions in sectors. An exception is made for energy sector emissions, where emissions from electricity and heat are addressed from both the producing side (energy supply) and from the consuming sides (other sectors). This means that successful halving of each sectors' emissions would give more than a 50% reduction overall.

BASELINE EMISSION DATA

The primary data source used in this study to estimate the global total GHG emissions and effects is PBL (Netherlands Environmental Assessment Agency) and the JRC (Joint Research Centre of the European Commission) [1]. This primary data source combines data from, mainly, the IEA (International Energy Agency, CO_{2e} from fuel combustion) [2], UN FAO (UN Food and Agriculture Organization, CH_4 and N_2O emissions) [3] and GCP (Global Carbon Project, land use) [4] together with estimates based on industry sources for industrial processes and so called "F-gases" (together with US EPA) [5]. See global GHG emission estimate summary in the table below, where emissions have been distributed so that double counting between categories is avoided.

Both PBL and IEA use national emission statistics reported under United Nations Framework Convention on Climate Change (UNFCCC) [6] as their main data source. PBL and JRC also compile, update and publish the well-used global emission data set, EDGAR (Emissions Database for Global Atmospheric Research) [7].

Table 1. Global Greenhouse gas emission estimates[1] for 2015 per category, in million tonnes (Mt).

Emission category	CO_{2e} (Mt)	References
Global CO_2 energy estimate	32 295	IEA (UNFCCC) [2]
Global CO_2 industrial processes estimate	3 335	PBL (UNFCCC) [1]
Global methane (CH_4) estimate[2]	9 126	PBL (UN FAO) [1]
Global nitrous oxide N_2O estimate[2]	2 862	PBL (UN FAO) [1]
Global "F-gases" estimate	1 314	PBL (US EPA) [1]
Global land use estimate (CO_{2e})	3 900	PBL (GCP) [1]
Uncertain fires (CH_4 and N_2O estimates)[2]	200	PBL (GCP) [1]
Total	53 000	

1 The term estimate is used here for all emission categories

2 About 476 Mt CO_{2e} from CH_4 and N_2O emissions related to savannah fires are included in the global CH_4 and N_2O emission estimates and are not included in Uncertain fires.

In order to establish a more detailed emission data set on sector and sub-sector levels from the above overall emissions, a number of references have been used for key data and assumptions. The following key data and assumptions for the main sectors in 2015 need to be mentioned:

- The energy sector's (as defined in the study) "own" emissions is estimated to about 5.9 Gt CO_{2e} of which about 3.0 Gt CO_{2e} comes from non-CO_2 sources, mainly methane (CH_4) from extraction, production and distribution [1, 2].
- Most other methane (CH_4) and nitrous oxide (N_2O) emissions, about 7.44 Gt CO_{2e}, have been allocated to the "food and agriculture" sector, apart from about 0.79 Gt CO_{2e} allocated to the industry sector and about 0.27 Gt CO_{2e} allocated to the buildings sector [1, 3].
- All CO_2 emissions from industrial processes have been allocated to the industry sector except direct gas flaring (about 290 Mt CO_{2e}) related to oil and gas production [1].
- About 1025 Mt CO_{2e} (25%) from land use and fires have been allocated to the forestry industry subsector as estimated by (CCAFS) [8], remaining land use and fire related CO_{2e} (75%) have been fully allocated to the "food and agriculture" sector.
- Allocation of "F-gases" have been estimated according to their use in buildings (about 500 Mt CO_{2e} air conditioning media), in transport vehicles (about 250 Mt CO_{2e} air conditioning media), in food supply (about 100 Mt CO_{2e} refrigerants) and in industry (all remaining use, 414 Mt CO_{2e}) [5, 9].
- The ICT and E&M (Entertainment and Media) sector emissions is taken from Malmodin and Lundén 2018 [19]. This sector's emission can be seen as a highlight

of emissions related to a more specific end-use subsector with emissions coming mainly from the building and the industry sector, rather than as a part of the overall allocation. About 0.3 Gt CO_{2e} from CH_4 and N_2O emissions related to fossil fuel combustion remains unallocated (included in the total 53.0 Gt CO_{2e}) [1]. A simple way to include these emissions could be to add +1% CO_{2e} to all energy related emissions in the sector and subsector emission details (not done in this study).

- Finally, about 476 Mt CO_{2e} from CH_4 and N_2O emissions related to savannah fires remain unallocated [1]. These GHG emissions could possibly be allocated to the food sector.

The allocation of emissions to the four main end-use sectors is described in Figure 1.

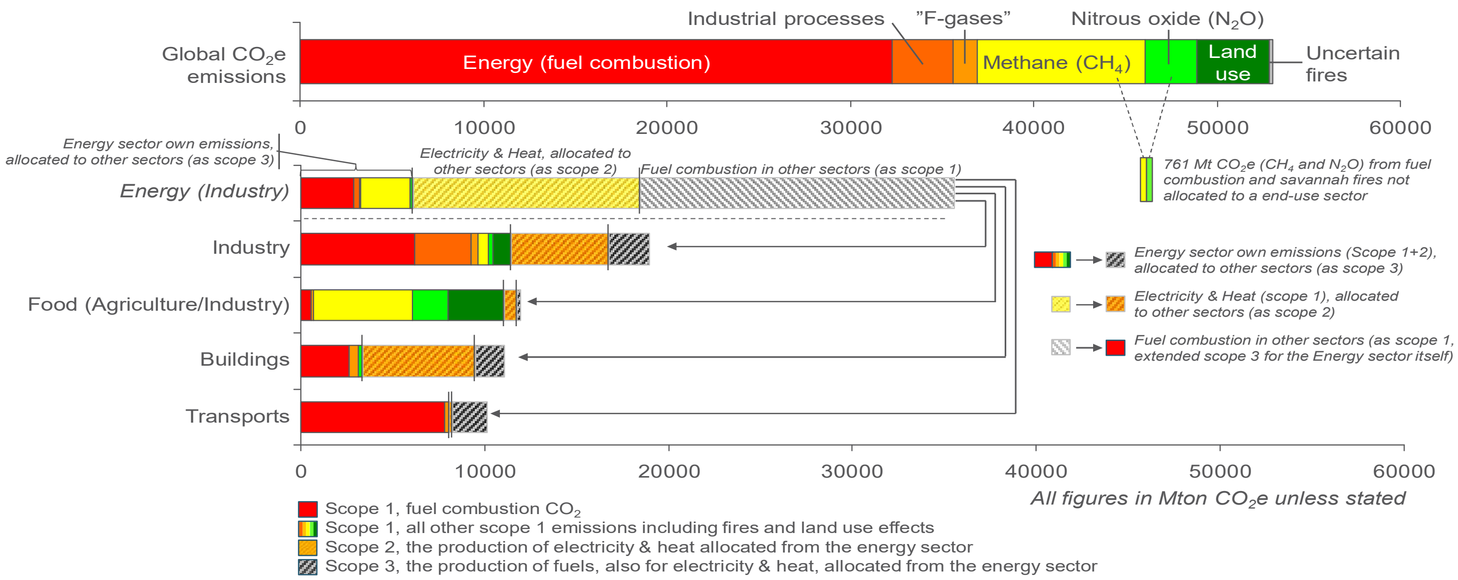

Figure 1. Global top-level and energy sector allocation of GHG emissions based on PBL and IEA and other GHG emission references.

At the time of the study, detailed emission data as late as for year 2015 could be established. High-level emission estimates exist for 2016 and a first top-level estimate exist for 2017. 2016/2017 estimates have however not enough detail (yet) to fulfill the needs of this study. Emissions in 2016 is estimated to only increase slightly over 2015 (<0.5% taking the fact 2016 was a leap year into account) and even if emissions are estimated to increase more in 2017 (+1% to +2% in 2017 vs 2015), emission data for 2015 is still a good approximation of today's global emissions. Therefore, 2015 emission data has been applied as baseline for current emissions, and as the starting point for emissions reductions in the beginning of 2020.

CLIMATE SOLUTIONS DATA

We used 76 climate solutions (sorted in 33 overarching solution categories), which, in combination, exhibit a cumulative ca 2000 Gt greenhouse gas (CO_{2e}) reduction potential during 2020-2050. 59 (82%) of those solutions were from Project Drawdown Optimum Scenario [11] with a cumulative potential of ca 1300 Gt CO_{2e} reduction during 2020-2050, while the remaining solutions and their CO_{2e} reduction potential data were from Finland's fund for the future (SITRA) [12], Roadmaps for Fossil Free Sweden competitiveness (Fossilfritt Sverige) [13], International Energy Agency (IEA) [14], World Wildlife Fund (WWF) Climate Solver [15] and own estimates based on IRENA historical growth figures [16].

TRAJECTORIES CONSTRUCTION METHOD

The identified potentials were available as cumulative CO_{2e} emissions reduction potential per solution (or per category) until 2050. We first scaled the cumulative CO_{2e} reduction potential of the solutions in a sector to obtain the solutions' maximum total potential to contribute towards that sector's baseline CO_{2e} reduction. The potential of a solution to contribute towards the sector's emission reduction corresponds to the percentage cumulative contribution of that solution in that sector's cumulative emission reduction during 2020-2050. Subsequently, the decadal targets (for 2030, 2040 and 2050) for CO_{2e} reduction from the baseline were set according to carbon law (ref), i.e. to reduce sector's baseline CO_{2e} emission by half every decade. The CO_{2e} emission reductions applying the solutions for the remaining years during 2020-2050 were estimated using the following polynomial backcasting model [17, 18]:

$$f(x) \approx \beta_0 + \beta_1(x - x_0) + \frac{1}{2}\beta_2(x - x_0)^2 \text{ for } x \in [x_0 - h(x_0),\ x_0 + h(x_0)] \qquad (1)$$

f(x) is the function of a solutions baseline CO_{2e} reduction potential (x) in a year. The polynomial parameters 0,1and 2were estimated using the smoothing window x0-h(x0), x0 + h(x0)including the smoothing parameter h.

The baseline emission was assumed to peak at the end of 2019 and begin to draw down on a year-to-year basis following the carbon law trajectories from 2020. The pace of increase in baseline CO_{2e} reduction for solutions during 2020-2025 was assumed as half of the pace during 2026-2050 since we assumed that many required technology and social innovation will not be available or show slow progress during 2020-2025. However, the CO_{2e} reduction pace during 2041-2050 is also slower than during 2020-2040 as carbon law targets the majority (75%) reduction during 2020-2040 and thus emphasizes early climate action.

CO_{2e} halving scenario was developed for each sector by 2030. Note that, a solution entailed CO_{2e} reduction in a sector may reduce CO_{2e} in other sectors. However, we carefully avoided such double counting by restricting a solution's CO_{2e} reduction only to the sector it belongs to (avoiding cross-sectoral emission reduction and assuming a constant energy demand, see chapter 4: energy systems for details).

ENERGY SUPPLY

The energy sector followed in parts a different methodology than other sectors and will therefore be described in detail. Five solutions were explored in detail for the energy supply (energy sector) emissions halving, and an additional "other" post. These contributed altogether 9.09 Gt reductions to the 5.88 + 12.31 Gt CO_{2e} emissions (sector's "own" emissions + electricity & heat) for 2015, i.e. exact halving of emissions.

The solutions were (with source):

- Solar photovoltaics, PV (in-house assessment based on IRENA growth data [16])
- Concentrating Solar Power, CSP (in-house assessment based on IRENA growth data [16])
- Wind power (in-house assessment based on IRENA growth data [16])
- Reduced methane leakage (Sitra Green to scale report [12])
- Grid efficiency and storage (in-house assessment based on literature review)
- Other low-carbon energy (Project Drawdown solutions scaled for 2030 [11])

For all solutions, only new capacity added after 2020 is measured as providing emissions reductions.

The calculations for solar and wind technologies are based on exponential growth trajectories. PV and wind are assumed to grow by 23.3%/yr and 10.2%/yr respectively from 2016, which in both cases is 0.457 of the mean growth for the 10-year period 2006-2016 [16]. These figures are arrived at through backcasting, aiming at halving the sector's emissions and treating the other solutions (CSP, methane, grid and other) as given. CSP is assumed to grow linearly (+0,78 TWh/yr) until 2020, after which it grows exponentially by 40% per year (based on that historical 10-year average growth has been 38%/yr). Renewables are assumed to replace fossil electricity with an average emissions factor of 877 g CO_{2e}/kWh [2]. The energy and emissions from producing new renewable capacity is handled by considering energy pay-back time: for a given year, the capacity added in the last 1 year (PV) or ½ year (CSP and wind) does not contribute to emissions reductions.

For reduced methane leakages, the figure 0.45 Gt reduced emissions for 2030 is adopted from Sitra Green to scale [12]. The trajectory from 2020 to 2030 is drawn using equation (1) above with β_0= 0.02, β_1 = 0.01, and β_2 = 0.00075.

Calculations for grid efficiency and storage assumes an additional 5% variable renewable energy (the sum of 0.05 of annual values for PV and wind) and that electricity demand is reduced by 5%. Emissions savings by reduced demand is assumed to come from reduced consumption of fossil-based electricity with an emission factor of 1058 gCO_{2e}/kWh (emission factor for a kWh of fossil electricity at end consumer) [2].

The other low-carbon energy post includes new nuclear, hydro, geothermal, biomass and cogeneration capacity and is based on scaled Project Drawdown solutions [11] (according to methodology presented above). None of these are above 0.22 Gt/yr individually in 2030.

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