Modelling net zero emissions

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Introduction

In the last years the aim of *"reaching net zero emissions"* gained political momentum. The Paris Agreement aims for *"a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century"* (Article 4 No 1). Also the EU Governance Regulation mentions *"net zero greenhouse gas emissions within the Union by 2050"* (Regulation (EU) 2018/1999, Article 15, No 2 (a)). These political intentions are backed by the scientific consensus. The newly published IPCC (2018) special report on *Global Warming of 1.5°C* (SR15) states *"Reaching and sustaining net zero global anthropogenic CO_2 emissions and declining net non-CO_2 radiative forcing would halt anthropogenic global warming on multi-decadal timescales"*.

Building compliance with the Paris Agreement will require to develop policies and measures aiming for this "net zero" goal. It is therefore crucial that long term scenarios explore the options and set the possible pathways to meet this objective. This is not only about upgrading existing scenarios: modelling "net zero" is a new challenge, raising new issues about the comprehensiveness, geographic perimeter or timescale of the scenarios, as well as calling for considering further technical or societal options. This is highlighted through some general comments about the concept, and the example of some scenarios.

Definition and implication of net zero emissions

The concept of "net zero emissions" is based on the fact that radiative forcing is due to "net emissions", which is the balance between raw emissions of greenhouse gas (GHG) and removal by sinks, or so-called "negative emissions". Reaching net zero anthropogenic emissions is therefore a matter of combining a reduction of raw anthropogenic GHG emissions and an increase of removals, either by reinforcing the role of natural sinks, or by creating artificial ones, through so-called carbon capture and storage (CCS) and bio-energy with carbon capture and storage (BECCS) technologies.[1]

The "net zero" goal is more than a simple extension of 75% to 80% targets to 100%. The traditional approach has been to focus on emissions reduction targets, and to give priority to energy-related CO_2 as the main contribution to existing emissions. The gap between a 75% or 80% reduction emissions scenario and a net-zero one is not to be easily bridged by additional measures. Instead it calls for a strong shift that needs a more comprehensive and holistic approach. The whole of emissions of all gases in all sectors, the potential for increasing natural sinks or developing artificial ones, and the crossed effects between all them have to be taken in account. Not only technological solutions but also issues such as urban planning, land use, circular economics or change of lifestyles have to be considered. Although this proves more difficult to model than the traditional sectorial approach, this shift needs to reflect on modelling of scenarios for them to better inform policy makers on what "net zero" means.

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[1] CCS is the process of capturing the CO_2 released from the exhaust gas of fuel combustion or other oxidative process and depositing the CO_2 in geological storages. BECCS is the combination of bioenergy use and capturing and storing the biogenic CO_2 leading to a net CO_2 sink. These technologies are not yet up to technological and industrial readiness levels that would allow for deploying them on the kind of considered scale.

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Carbon neutral or climate neutral

Instead of the rather technical term *net zero emissions* very often more colloquial terms as *carbon neutral* or *climate neutral* tend to be used. These two concepts are not identical. Moreover, due to a lack of specific, clear and well shared definition, they can be understood and used in a different way depending on the context.

A classical definition of both concepts could be the one introduced by Butler et al. (2015):

- ***Carbon neutral*** means that all activities lead to net zero CO_2 emissions. This can be achieved by either reducing CO_2 emissions to zero or compensating remaining CO_2 emissions by sequestering the same amount of CO_2 permanently from the atmosphere and depositing in a sink. While carbon neutrality implies net zero CO_2 emissions there can still be significant amounts of non-CO_2 emissions like methane (CH_4), nitrous oxide (N_2O) and fluorinated gases. ***Decarbonisation*** is the process of reducing CO_2 emissions and aiming for carbon neutrality.
- In contrast the term ***climate neutral*** covers not only CO_2 but all greenhouse gases. Climate neutrality is achieved when the activities result in net zero GHG emissions. This does not mean that every single greenhouse gas has to reach net zero but the sum of all greenhouse gases. The different effects of greenhouse gases can be compared by the metric of global warming potentials (GWP)[2], which is used to measure all emissions in “carbon equivalent”.

The differentiation between carbon neutral and climate neutral is remarkably relevant in modelling: many energy models were developed to calculate only CO_2 emissions while neglecting non-CO_2 emissions. For example energy models would typically treat bioenergy use as a zero emission fuel, though depending on conditions, this process can generate significant emissions of very potent greenhouse gases (CH_4 and N_2O), or reinforce natural sinks .More generally, the concept of climate neutrality requires to address the much more complex accounting of life cycle emissions and removals, rather than a simpler measurement of gross CO_2 emissions. Also, as this comprehensive approach is increasingly developed, the concept of carbon neutral tends to be used in the sense of a carbon equivalent neutrality, that is similar to climate neutrality[3].

Perimeter of net zero emissions

Any of the above concepts can be applied to countries, a federation of countries like the European Union, but also regions, cities, organisations and even individuals. However, any of these entities, whatever its size, is not living in autarchy. It exchanges materials, goods, services and possibly people with other entities around. The exported items generate domestic emissions that fulfill these entities’ demand, while imported items serve the domestic demand but have generated emissions elsewhere. Also, the exchanges themselves generate emissions.

It is therefore different to set a net zero objective in terms of domestic emissions, or to search for a net zero “carbon footprint” (which is obtained by subtracting CO_2 export-related emissions to the domestic ones, and adding import-related emissions), or “climate footprint” (including all export and import-related GHG emissions).

The main reason why footprint has to be considered is that net-zero emissions is a goal that needs to be achieved on the global level. Achieving net zero on the domestic level of a given entity has an impact on

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[2] Although this can in turn raise additional questions, as the respective GWP of greenhouse gases depends on the time-scale used for comparison, which might have an influence on the global balance, when talking about cumulative emissions on the long term.
[3] This is for instance the case in France, where the Government is considering the introduction of a net zero objective in the law that would use the wording “neutralité carbone”.

its exchanges with other entities, thus on the potential for achieving net zero on a domestic level of these entities[4]: one has to consider these impacts when designing its own net zero strategy.

This could be considered from a wide range of perspectives. One is to rely on offsetting remaining domestic emissions through compensation, i.e. the financial and technical contribution to reduce emissions elsewhere; however, this could be seen as a way to avoid the further effort on domestic emissions that is needed to bring the global carbon footprint down to net zero. Conversely, a more ambitious approach would consist in trying for a country or another entity to get its own climate footprint down to net zero; although this could rely on more domestic production of energy, goods and services, this would however still involve some exchanges, the GHG balance of which is hard to include in a modelling exercise on the national scale.

At least, it is clear that exchanges, and their impact on GHG emissions, need to be better taken into account in scenarios. This particularly applies to international airplane and maritime transport of passengers and freight, that is most of the time not included in existing models (one reason being that the corresponding emissions are not included in the national accounting framework set by the international community). Another issue deserving more attention is the potential for some mutualisation of efforts and opportunities, taking into account the fact that depending on their history, level of development, geographical situation etc., countries face very different challenges to get down to net zero. This question is particularly relevant on the EU level.

Net zero emissions and emission budgets

Limiting global warming to a threshold like 1.5°C or 2°C above preindustrial levels can only be achieved when global GHG emissions eventually reach net zero. But not only is the endpoint when reaching net zero emissions relevant but also the emission trajectory which determines the cumulative emissions in the time period. The cumulative GHG emissions possible until reaching a specific warming threshold is called *global emission budget*. One aim of scenario modelling is to derive pathways under given emission budgets. Also finding the appropriate year to achieve net zero emissions can be the task of modelling. Conversely, scenarios can be used to discuss the combination of options and the pace of implementation that would allow for minimising the cumulative emissions (or global emission budget) while reaching net zero in a given year (i.e. help to find the optimal balance between actions that would provide the fastest reduction in the short term and those that are needed to further reduce and remove in the longer term).

Moreover, reaching net zero at some point is only part of what's needed to maintain global warming below 1.5°C at the end of the century. Net negative emissions might be needed after reaching this point – the higher the cumulative net emissions before getting to net zero, the higher and longer the need for net negative emissions afterwards. This questions the period that scenarios need to cover – usually limited to 2050 in existing ones –, and the capacity to model such situations over such a term.

The SR15 shows with its four representative pathways[5] (figure 1) that net negative emissions can be achieved through very different mixes of technological and non-technological decisions (from options like a broad use of BECCS to changes of consumption patterns). Although reaching net zero emission in the same year, larger cumulative emissions before reaching net zero emissions implies that larger negative CO_2 emissions (carbon dioxide removal, CDR) is needed after reaching net zero emissions to compensate the "emission debt". While they are all consistent with limiting global warming to 1.5°C by 2100, the pathways have a different impact on climate over the century: those where cumulative levels of gross emissions are higher, before they are compensated by higher level of negative emissions, increase the risk of a so-called "overshoot", i.e. global warming temporarily getting over 1.5°C.

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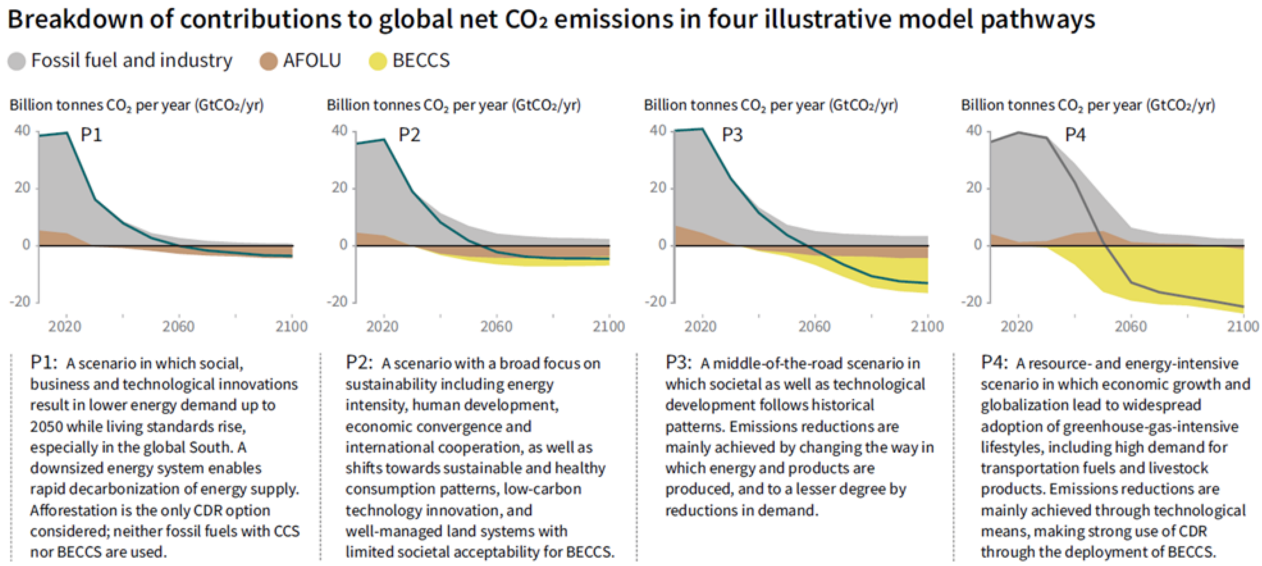
[4] The relocation in countries like China of some of the European industry, which still serves for some part European demand, is a classic example of a policy that reduces domestic emissions of Member States but provides no global benefit in terms of climate footprint.
[5] Based on the examination by IPCC of almost one hundred scenarios published in scientific literature.

Figure 1 Four representative pathways from IPCC Special Report *Global Warming of 1.5°C*



Source: IPCC (2018): Global Warming of 1.5°C, Summary for Policy makers, part of Figure SPM.3b

Global carbon budgets can be broken down to national levels. Matthes et al. (2017) discuss various concepts including shares of current emission levels, equality-based concepts and performance-related principles. Target years for reaching net zero emissions can be determined by combining national emissions budgets and an indicative emission reduction path.

The need to think of pathways not only in terms of reduction of emissions, or even in terms of net balance of emissions, but also to take into account the cumulative effects to comply with a carbon budget is of course yet another challenge for modelling. In particular, it calls for an optimisation of the balance between taping the potential of short term abatement options and preserving the potential for longer term reductions options that traditional models, and the merit order they would introduce, are not really prepared for.

National and regional scenarios with (almost) net zero emissions

The need for elaborating net zero pathways and considering carbon budgets is increasingly reflected in recent efforts of modellers, who take the challenge on different scales, from those of local communities to the World, through national and regional exercises, e.g. on the European level, as illustrated by Allen et al. (2018). The following provides input on methodological issues and technological or non-technological options as considered in three examples of recent national or regional scenarios in Europe.

Climate Protection Scenario 2050 for Germany

In 2015 Öko-Institut and Fraunhofer ISI published the study *Klimaschutzszenario 2050, 2. Modellierungsrunde* with scenarios for Germany covering the period until 2050. A translated English version *Climate Protection Scenario 2050, Summary of second final report* was published in 2016. This study contains next to other scenarios the scenario CS 95 which aims for 95% greenhouse gas emissions reduction compared to 1990.

The study has a broad scope and includes greenhouse gas emissions (CO_2, CH_4, N_2O, F-gases) and also includes those emissions from the German share of international aviation and maritime transport. Due to this broad scope and the deep carbonisations this scenario can be treated as almost net zero. In the CS 95 scenario, the CO_2 emissions were reduced by about 99%, so the scenario almost achieves carbon neutrality. As non-CO_2 gases are much harder to reduce, the sum of non-CO_2 emission is by 2050 only 78% lower than in 1990. The remaining non-CO_2 emissions are about three times larger than the remaining CO_2 emissions.

Table 1 GHG emission reductions in the scenario CS 95

Sector	Base year: 2010			Target year: 2050			Relative change compared to 1990		
	CO2	other GHG	all GHG	CO2	other GHG	all GHG	CO2	other GHG	all GHG
	Mt CO2e						%		
Energy industries incl. fugitive emissions	353.2	13.2	366.4	17.5	1.5	19.0	-96%	-96%	-96%
Industry incl. process emissions	176.3	17.5	186.4	-0.9	3.9	3.0	-100%	-90%	-99%
Buildings	150.5	1.6	152.1	5.5	0.4	5.9	-97%	-89%	-97%
Transport incl. international air and maritime	186.9	1.8	188.6	14.3	0.5	14.9	-92%	-79%	-92%
Waste		15.4	15.4		3.9	3.9		-91%	-91%
Agriculture		68.4	68.4		35.5	35.5		-60%	-60%
LULUCF	8.4	0.3	8.7	-23.2	0.2	-23.0		-36%	-36%
Total incl. memo items	**875.3**	**118.1**	**985.9**	**13.2**	**45.9**	**59.1**	**-99%**	**-78%**	**-95%**
Energy	805.4	17.5	822.9	33.6	2.6	36.3	-97%	-94%	-97%
Non-energy	69.9	100.6	163.1	-20.5	43.3	22.9	-177%	-74%	-88%

Remarks: Red: emission change less than -95%; yellow: emission change between -95% and 100%; green: emission change more than -100%, i.e. sector becomes an emission sink.

Source: Own calculations based on the data from Climate Protection 2050 (Repenning et al., 2018).

A key strategy across all energy sectors is promoting energy efficiency leading to halving energy consumptions. Remaining energy demands are covered trough a strong deployment of renewable energies (approx. 90% of energy consumptions). Biomass use is limited through restricted biomass imports. Electrification across all sectors and in the transport sector also synthetic fuels play an important role.

Carbon capture and storage (CCS) is in the CS 95 scenario the key technology to reduce CO_2 emissions of industrial processes. A key strategy in the agriculture sector is the reduction of animal numbers enabled by reducing export meat products and by less domestic meat consumption

The protection of moor soils through conversion of agricultural land to wet land and forests leads to significant negative emissions. The combination of bioenergy use and CCS (BECCS) is used in the iron and steel industry as well as in cement production leading to a small emission sink in the industry sector. This sink is limited through strict biomass constraints.

The modelling of the scenario was not only focused on technological solutions but also reflects social and behavioural changes: Examples of sufficiency measures are the already mentioned reduction of meat consumption and promotion of reduced room temperatures in buildings. A transformation to compact cities enables the reduction of the motorised transport and growth of public transport and bicycle use.

négaWatt 2017-2050 scenario for France

The *négaWatt 2017-2050 scenario*, which was published in France by Association négaWatt in early 2017, was the first to propose a “net zero emissions” pathway for the country. An English summary report of the scenario was published in 2018 (Ass. négaWatt, 2018a). The study compares a scenario where mostly existing or planned measures would be implemented with one where stronger changes are sought to address multiple sustainable issues (use of raw mineral materials, air pollution, land use…), with a primary focus on climate change.

The scope of the scenario is encompassing most GHG emissions and natural removals through a combined modelling of the energy system (production and consumption in all sectors), the agriculture and forests (thanks to the coupling of the négaWatt scenario with Afterres 2050, a scenario for forest, agriculture and the use of biomass in France developed by Solagro), and the industry. While CO_2, CH_4 and N_2O emissions are comprehensively covered by this approach, the scenario does also include some modelling of F-gases. Also, the emissions include the French share of international plane passenger transport, but neither plane freight nor maritime transports. Finally, it is not including the broader GHG footprint of the French economy, which was found too hard to reflect in a modelling approach, especially regarding services (compared to difficult but possible calculations for raw materials and goods).

Altogether, the scenario achieves neutrality, or net zero emissions on its scope through the combination of an almost complete decarbonisation of the energy system (-99% on energy related CO_2), more than halving emissions of other GHG (-60% compared to 2015), and increasing the removal of CO_2 by natural sinks thanks to changes in agricultural modes and forestry (+93% of negative emissions).

Table 2 GHG emission reductions in the scenario négaWatt 2017-2050

Sector	Base year: 2015			Target year: 2050			Relative change compared to 1990		
	CO2	other GHG	all GHG	CO2	other GHG	all GHG	CO2	other GHG	all GHG
	Mt CO2e						%		
Energy industries incl. fugitive emissions	45,1	1,5	46,6	1,4	0,4	1,8	-98%	-94%	-98%
Industry incl. process emissions	78,0	23,8	101,7	15,3	3,8	19,2	-86%	-90%	-87%
Buildings	85,9	2,9	88,8	0,0	1,3	1,3	-100%	-80%	-99%
Transport incl. international air and maritime	155,2	2,0	157,2	0,0	0,3	0,3	-100%	-87%	-100%
Waste	1,6	15,9	17,4	0,9	0,0	0,9	-61%	-100%	-95%
Agriculture	2,0	76,1	78,1	4,7	42,9	47,6	+163%	-47%	-43%
LULUCF	-45,1	4,3	-40,8	-79,0	0,0	-79,0	+163%	-100%	+206%
Total incl. memo items	**322,6**	**126,4**	**449,0**	**-56,8**	**48,8**	**-8,0**	**-115%**	**-69%**	**-101%**
Energy	341,6	6,9	348,5	4,1	4,7	8,9	-99%	-71%	-98%
Non-energy	-19,0	119,5	100,5	-60,9	44,0	-16,9	-1881%	-68%	-112%

Remarks: Red: emission change less than -95%; yellow: emission change between -95% and 100%; green: emission change more than -100%, i.e. sector becomes an emission sink.

Source: Own calculations provided by Association négaWatt.

The négaWatt scenario[6] is underpinned by a detailed analysis of energy consumption in each sector and of energy production to explore the possibility for voluntarist but realistic change. Its modelling is based on a specific, three-step approach: first, prioritising essential needs in individual and collective energy uses, through sufficiency (Ass. négaWatt, 2018b); second, reducing the amount of energy required to cover each need through energy efficiency; third, developing renewable energies and resources, which are seen as intrinsically more sustainable, to substitute to non-renewable ones.[7]

The scenario takes a cautious approach towards the potential for technologies that don't exist yet (or are close enough to technological, industrial and socio-environmental maturity), therefore excluding options such as CCS, and rather putting emphasis on the need for societal change (better urban planning, shift in transport modes, changes in good consumption patterns…). Through combined sufficiency and efficiency, final energy demand is halved by 2050, which allows for fulfilling it with 100% of renewable energies, mostly provided on a same level by electric renewables and biomass (a mix of mostly solid biomass and biogas, all arising from secondary or by-products of forestry and agriculture). Power-to-gas is seen as a key to balance the system in the long term. Increased use of biomaterials, and changes in food habits and agriculture modes contribute to reducing the remaining non CO_2 emissions.

Nordic NETP/IPCC 2014 scenario for the Scandinavian region

Three flagship projects (NegativeCO2, SHIFT and Flex4RES) have been launched through the Nordic Energy Research platform, for a 4-year period, to address common Nordic energy and climate challenges.[8] These projects touch on specific needs for addressing the issue of how can the Nordic countries live up to the Paris agreement, and more specifically what is the need for biofuels?

Like in a bathtub – where one needs to stop the tab and start draining the bathtub –, the analyses drawn from these projects are based on carbon budget. The sizes of the carbon budgets considered can be seen in the Figure below. They are calculated from IPCC reports, using a split "50% emissions 50% population". In the business-as-usual scenario the Nordic countries will spend their budget (1.5°C 66%) be-

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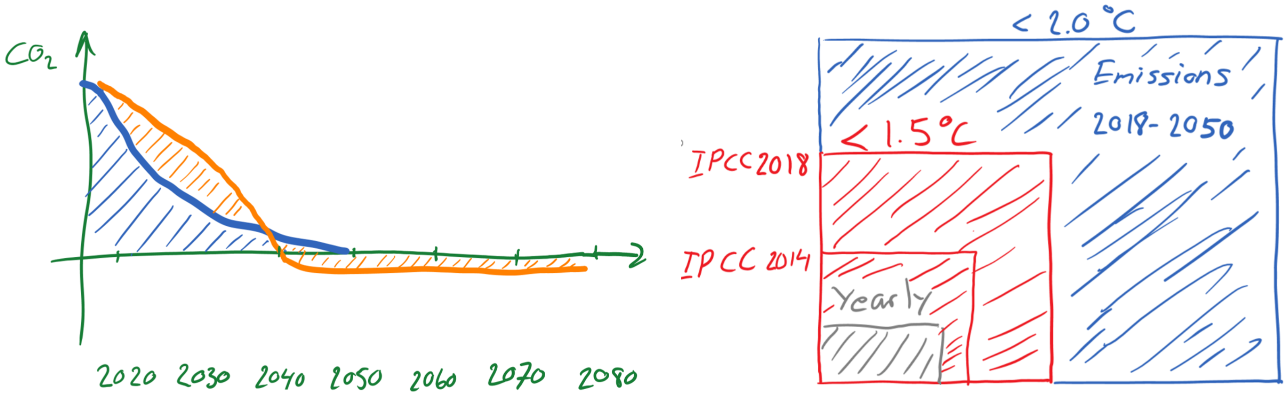
[6] More information about the scenario at: https://negawatt.org/The-negaWatt-2050-energy-scenario

[7] There is a clear difference, although their use raises sustainability issue too, in the fact that renewable resources are based on flows, that won't run out compared to the stocks of finite resources such as coal, oil, fossil gas and uranium.

[8] The projects, that involve a broad range of industrial partners, research institutions and civil society organisations, aim for enabling a rigorous scientific basis to be applied to practical industrial challenges. They address specific areas that are seen as critical to further steps in Nordic energy system transition: the flexibility and market interaction needed for further integrating variable renewable energy (Flex4RES), the need for an energy-efficient and low-carbon transport system (SHIFT), and the potential for negative CO_2 emissions through the use of chemical-looping combustion of biomass (NegativeCO2).
More information about these projects: http://www.nordicenergy.org/projects/

tween 2025 and 2029. For that reason, they need to go CO_2 negative to "buy time". Other options are regarded as hardly feasible.

Figure 2 Emission paths and emission budgets



The feasibility of future energy scenarios aiming at reaching net carbon neutrality in the Nordic region by 2040, in compliance with the well below 2°C carbon budgets (IPCC, 2014), was therefore explored through the coupling of the power and heat model Balmorel (Wiese et al., 2018) with the technology-rich energy system TIMES-Nordic, a partial equilibrium model of the TIMES model family (Loulou et al., 2016).

The critical points identified include the issue of national and international aviation and shipping, the availability of sustainable biomass according to the needs, and the sector coupling and integration. The analysis also points to the need for capture and storage, the priority for greening transport, and the key role of disruptive technology development.

Three scenarios were analysed: the Nordic NETP uses demand projections and fuel prices from the Nordic Energy Technology Perspectives (IEA, 2016), with carbon tax. It serves as a basis to model the Nordic IPCC 2014 scenario, which uses the same projections, but with a carbon budget, and the Nordic IPCC 2014 Bio scenario, which includes, on top of the previous one, no biomass and biofuels import.

The main results[9] include the need for a strong increase of the capacity of power transmission lines, together with a large increase in power trade with neighbouring countries, while wind, PV, and sustainable biomass will play very important role. Power and heat sector is almost decarbonized by 2020 in IPCC 2014, but in IPCC 2014 Bio, inland transport sector is not fully decarbonized even in 2050, and with a huge utilization of biogenic CCS. The main difference in biofuels use between the two scenarios lies with wood pellets and wood waste. The analysis also suggests the need for future research in areas such as electro fuels, hydrogen and ammonia, the boundary conditions of sustainable use of biomass, but also smart policies.

General conclusions from all three scenarios

The three examples above illustrate some of the changes that might be needed to get to net zero in some countries. They also show how different combinations of technological and societal options can be used, and suggest that both the perceived technical feasibility and economic soundness of the different options by the modellers, and the approach developed in the models themselves have an influence on these combinations. Besides some significant differences, the scenarios also share some common patterns. Altogether, a number of interesting remarks can be drawn from their comparison, and the way they handle the various challenges for modelling arising from a net zero objective:

[9] The results of the scenarios can be seen at: https://timesnordic.tokni.com/

- The modelling of pathways showing compliance with the Paris Agreement needs not only to aim for a net zero objective for GHG emissions at some time, but also to care about the cumulative emissions before reaching that level, and the sustained negative emissions afterwards. The carbon budget approach is a relevant way to quantify these aspects.
- The shift to a net zero objective calls for a much broader and cross-sectorial modelling approach, taking into account the fact that non-CO_2 emissions are much harder to reduce than CO_2 emissions.
- Looking for cross-sectoral interlinkages is essential to provide comprehensiveness and consistency for the proposed global reduction pathways. This is even more critical to develop pathways that do address non climate sustainable issues too (land use, water, raw materials, etc.).
- Some CO_2 emissions that are often not included in national energy system models, such as airplanes and ships (particularly international) need to be taken into account, especially because this is a sector where substituting oil will be most challenging (appropriate biofuels or synthetic power-to-liquid options for planes are not ready yet).
- To reach net zero GHG emissions, remaining non-CO_2 emissions have to be reduced by CO_2 sinks. These could either rely on increased natural removal of CO_2, the potential of which is depending on countries and might be limited in time, or CCS and BECCS technologies that have yet to be developed and prove to be deployable on the required scale. A detailed modelling of the implementation of these options and their impacts over time is needed.
- The reduction of CO_2 from energy combustion (but also other process-related GHG emissions) potentially results from the combination of an action on demand, to reduce the need for the energy (or any other product of a GHG emitting process), and an action on supply, to substitute the combustion (or process) by a non or low-emitting energy (or process). Modelling needs to inform the possible combination of these types of action.
- Energy efficiency is part of the solution as it is difficult to fulfil today’s energy consumption with low-carbon technologies.
- Further action on demand for energy and materials, through sufficiency, has to be considered for its potential to reduce the need for substitution and the associated technological challenges. Scenarios appear to bear choices about the respective limitations or constraints related to lifestyle change on one hand and the implementation of disruptive technologies on the other hand, that are reflected in modelling approaches.
- There are more ready solutions for decarbonisation of the power sector and heat in buildings, and to some extent the use of energy in the industry, than the transport sector (which is the more dependent on fossil fuels).
- The potential for developing electric renewables, especially wind and PV that have a very important role to play, is in general less constrained than the sustainable use of bioenergy. Biomass should therefore be used prioritarily in sectors where emissions are hardest to reduce through action on demand or substitution by electricity.
- The amount of sustainable biomass available for energy (and materials), and the availability of bioenergy for BECCS that is considered in the longer term in some pathways, need to be as clearly assessed as part of the modelling as possible. This also needs to be articulated with an analysis about the potential for supplying synthetic fuels.
- Both the supply of electricity and that of biomass for energy need to be considered on a broader level than the national one, to take into account the differences in needs and potentials. The corresponding need for increased electric interconnection between countries, and the conditions for the transnational use of biomass to remain sustainable should be considered in modelling.

This chapter will be amended / completed after the discussion on TD3.

How to model net zero emissions

This section will be written after the discussion on TD3.

References and further reading

1. Duscha, Vicki, Alexandra Denishchenkova, and Jakob Wachsmuth, Achievability of the Paris Agreement targets in the EU: demand-side reduction potentials in a carbon budget perspective, Climate Policy (2018): 1-14.

2. Butler, Tim; Birgit Lode, Andy Parker, Kathleen Mar, Falk Schmidt, and Mark G. Lawrence (2015): *Long-term climate goals – Decarbonisation, carbon neutrality, and climate neutrality.* Institute for Advanced Sustainability Studies (IASS) Potsdam, November 2015, https://www.iass-potsdam.de/sites/default/files/files/policy_brief_decarbonisation.pdf

3. IPCC (2018): *Summary for Policymakers*. In: *Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Waterfield (eds.)]. World Meteorological Organization, Geneva, Switzerland, 32 pp. https://www.ipcc.ch/site/assets/uploads/sites/2/2018/07/SR15_SPM_High_Res.pdf

4. Matthes, Felix Chr., Lukas Emele, Hauke Hermann, Charlotte Loreck, Frank Peter, and Inka Ziegenhagen: *Germany's Electric Future – Coal phase-out 2035.* Öko-Institut & Prognos, October 2017, https://www.oeko.de/publikationen/p-details/germanys-electric-future/
(Especially chapter 4)

5. Allen, Paul; Bottoms, Isabelle et al. (2018): *Raising Ambition – Zero Carbon Scenarios from Across the Globe*. Center for Alternative Technology, November 2018,
https://www.cat.org.uk/download/25756/

6. Repenning, Julia; Lukas Emele et al. (2016): *Climate Protection Scenario 2050, Summary of second final report*. Öko-Institut & Fraunhofer ISI, July 2016,
https://www.oeko.de/publikationen/p-details/climate-protection-scenario-2050/

7. Wachsmuth, Jakob, and Vicki Duscha, Achievability of the Paris targets in the EU—the role of demand-side-driven mitigation in different types of scenarios, Energy Efficiency (2018): 1-19.

8. Ass. négaWatt (2018a): Chatelin, Stéphane; Couturier, Christian; Letz, Thomas; Marignac, Yves; Rauzier, Emmanuel; Salomon, Thierry et al. *The négaWatt 2050 energy scenario*, English Summary. Association négaWatt, November 2018.
https://negawatt.org/IMG/pdf/181128_negawatt-scenario_eng_12p.pdf

9. Ass. négaWatt (2018b): Bringault, Anne; Chatelin, Stéphane, Toulouse, Édouard et al. *Energy sufficiency : towards a more sustainable and fair society*. Association négaWatt November 2018.
https://negawatt.org/Energy-sufficiency-towards-a-more-sustainable-and-fair-society-557

10. IPCC (2014): *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland, 2014.

11. Wiese, F., Bramstoft, R., Koduvere, H., Pizarro Alonso, A. R., Balyk, O., Kirkerud, J. G., Tveten, Å. G., Bolkesjø, T. F., Münster, M., Ravn, H. V. (2018). Balmorel open source energy system model. Energy Strategy Reviews, 20, 26–34.
https://doi.org/10.1016/j.esr.2018.01.003

12. Loulou, R.; Goldstein, G.; Kanudia, A.; Lettila, A. and Remme, U. (2016). Documentation for the TIMES Model Part I: TIMES Concepts and Theory, 2016.

13. IEA (2016): OECD/IEA, Nordic Energy Research, Technical University of Denmark, Ea Energianalyse A/S, VTT Technical Research Centre of Finland, University of Iceland, Institute For Energy Technology, Profu Ab and IVL Swedish Environmental Research Institute. *Nordic Energy Technology Perspectives*. IEA Publishing, 2016.

Fact sheet: *Climate Protection Scenario 2050* for Germany

Basic information and scope

Title:	Climate Protection Scenario 2050 (Second final report)
Authors:	Julia Repenning, Lukas Emele et al.
Institution(s):	Öko-Institut & Fraunhofer ISI
Year of publication:	2015/2016
Country / Region covered:	Germany in the scope of the national GHG inventory, including LULUCF and international transport
GHG emissions covered:	CO2, CH4, N2O, HFCs, PFCs, SF6

Net GHG emissions

	Year	CO2 [Mt CO2eq]	Non-CO2 [Mt CO2eq]	Total [Mt CO2eq]
Base year	1990	1025.8	208.8	1234.6
Latest historic year	2010	867.9	118.1	985.9
(Almost) net-neutral year	2050	13.2	45.9	59.1

Remaining GHG emissions per sector in (almost) net neutral year

Sector	CO2 [Mt CO2eq]	Non-CO2 [Mt CO2eq]	Total [Mt CO2eq]
Energy industries incl. fugitive emissions	17.5	1.5	19.0
Industry incl. process emissions	-0.9	3.9	3.0
Buildings	5.5	0.4	5.9
Transport incl. international air and maritime	14.3	0.5	14.9
Waste	0.0	3.9	3.9
Agriculture	0.0	35.5	35.5
LULUCF	-23.2	0.2	-23.0

GHG sinks per sector in net neutral year

Sink	Mt CO_2
LULUCF	30.1
BECCS	11.4

Shares of energy carriers in net neutral year

Energy carrier	Share PEC [%]	Share FEC [%]
Biomass	19%	20%
Other renewable energy	66%	10%
Fossil fuels	10%	7%
Nuclear	0%	–
Synthetic fuels	2%	4%
Electricity	0%	50%
District heating	–	9%
Waste and other	2%	0%

Energy efficiency in net neutral year

	PEC compared to 2010 [%]	FEC compared to 2010[%]
Reduction of energy consumption	-55%	-53%

Fact sheet: *négaWatt 2017-2050* scenario for France

Basic information and scope

Title:	négaWatt 2017-2050
Authors:	Stéphane Chatelin, Christian Couturier, Thomas Letz, Yves Marignac, Emmanuel Rauzier, Thierry Salomon et al.
Institution(s):	Association négaWatt
Year of publication:	2017
Country / Region covered:	France, including LULUCF and part of international transport
GHG emissions covered:	CO_2, CH_4, N_2O, HFCs, PFCs, SF_6, NF_3

Net GHG emissions

	Year	CO2 [Mt CO2eq]	Non-CO2 [Mt CO2eq]	Total [Mt CO2eq]
Base year	1990	415.9	150.7	566.5
Latest historic year	2015	367.7	122.1	489.8
(Almost) net-neutral year	2050	22.2	46.0	68.2

Remaining GHG emissions per sector in (almost) net neutral year

Sector	CO2 [Mt CO2eq]	Non-CO2 [Mt CO2eq]	Total [Mt CO2eq]
Energy industries incl. fugitive emissions	1.4	0.4	1.8
Industry incl. process emissions	15.3	3.8	19.2
Buildings	0.0	1.3	1.3
Transport incl. international air and maritime	0.0	0.3	0.3
Waste	0.9	0.0	0.9
Agriculture	4.7	42.9	47.6
LULUCF	-79.0	0.0	-79.0

GHG sinks per sector in net neutral year

Sink	Mt CO_2
LULUCF	-79.0
BECCS	—

Shares of energy carriers in net neutral year

Energy carrier	Share PEC [%]	Share FEC [%]
Biomass	41.5%	26.1%
Other renewable energy	57.3%	10.0%
Fossil fuels	0.7%	0.6%
Nuclear	0.0%	—
Synthetic fuels	—	15.6%
Electricity	—	44.2%
District heating	—	3.5%
Waste and other	0.5%	0.0%

Energy efficiency in net neutral year

	PEC compared to 2015 [%]	FEC compared to 2015 [%]
Reduction of energy consumption	-63%	-57%

Fact sheet: Nordic IPCC 2014 Bio for the Scandinavian Region

Basic information and scope

Title:	Nordic IPCC 2014 Bio
Authors:	Kenneth Karlsson, Raffaele Salvucci
Institution(s):	Technical University of Denmark
Year of publication:	2018
Country / Region covered:	Denmark, Sweden, Norway
GHG emissions covered:	CO_2

Net GHG emissions

	Year	CO2 [Mt CO2eq]	Non-CO2 [Mt CO2eq]	Total [Mt CO2eq]
Base year				
Latest historic year	2010	120.0		
(Almost) net-neutral year	2050	5.4		

Remaining GHG emissions per sector in (almost) net neutral year

Sector	CO2 [Mt CO2eq]	Non-CO2 [Mt CO2eq]	Total [Mt CO2eq]
Energy industries incl. fugitive emissions	3.5		
Industry incl. process emissions	8.0		
Buildings	1.4		
Transport incl. international air and maritime	37.6		
Waste	Included in power and heat (row 1)		
Agriculture	Included in industry		
LULUCF	Not incl.		

GHG sinks per sector in net neutral year

Sink	Mt CO_2
Biomass CCS (Power and district heating)	38.0
Biomass CCS (Industry)	7.0

Shares of energy carriers in net neutral year

Energy carrier	Share PEC [%]	Share FEC [%]
Biomass	17,4%	7,4%
Other renwable energy	63,3%	8,6%
Fossil fuels	29,7%	27,7%
Nuclear	0,0%	0,0%
Synthetic fuels	4,4%	5,5%
Electricity	-19,1%	31,3%
District heating	0,0%	19,5%
Waste and other	4,2%	0,0%

Energy efficiency in net neutral year

	PEC compared to 2010 [%]	FEC compared to 2010 [%]
Reduction of energy consumption	-26%	-23%