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A World of Opportunities – how to reach net-zero?

CHAPTER 4

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4. A World of Opportunities: how to reach net-zero?

Introduction

The world emits approximately 50 billion tonnes of greenhouse gasses (GHG) a year[1], with approximately three-quarters of emissions coming from energy use, and just under one-quarter from agriculture and land use to feed an increasing population (including processing, packaging, transport and retail), and the remaining 8% from industry and waste other than energy use (Fig1).

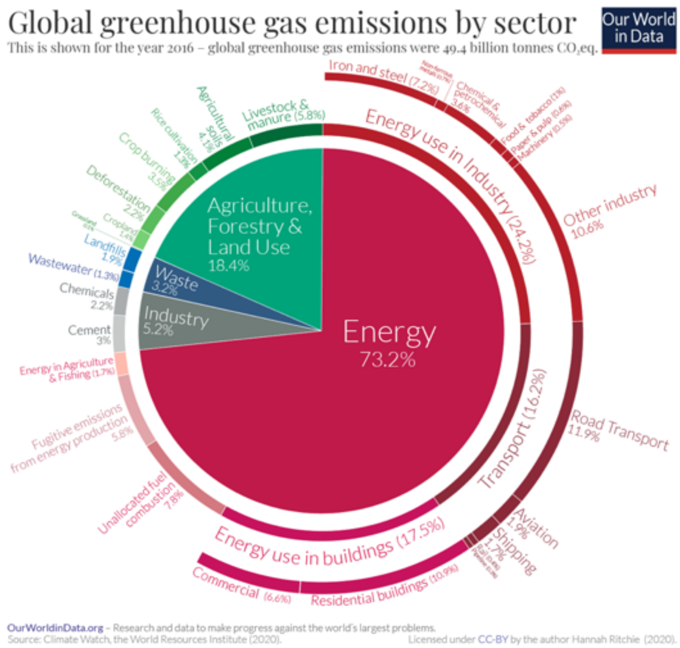


Fig 1: Emissions by sector[2]

Considering the vast range of sectors and processes contributing to global emissions, there is no silver bullet solution to reducing GHG emissions. Focusing on electricity, or transport, or food, or deforestation alone is insufficient[3]. Even within the energy sector, the largest contributor to GHG emissions, there is no single solution that can be adopted everywhere. If we manage to decarbonise electricity supply, we still need to find viable solutions concerning heating, road transport, shipping and aviation.

The scale of the mission to get to net-zero emissions is probably the largest we have ever taken on. Getting to net-zero means reducing GHG emissions to as close to zero as possible and balancing any remaining emissions by removing GHG from the air through the creation of new carbon sinks. We have taken on grand challenges in the past such as the Moon landing, banning ozone-depleting chemicals and designing a COVID-19 vaccine in record time which gives us hope that we can outperform yet again. Achieving net-zero emissions will require the fastest economic transition in history and will depend on the policies adopted, the speed of their implementation and the level of resources committed[4] within two key areas in particular, that is energy (including electricity production, heat, transport, and industrial activities) and food production (including agriculture and land use change).

[1] Measured in carbon dioxide equivalents CO2equivalent
[2] Ritchie H., Roser M., 2020. Emissions by Sector. Our World in Data
[3] Ritchie H., Roser M., 2020. Emissions by Sector. Our World in Data
[4] IRENA, 2020. Global Renewable Outlook – Energy Transformation 2050

The key actions needed within these two distinct areas will be the main focus of this chapter. It will include 1. how to improve efficiency i.e., using less energy to produce a given output, using equal or less land surface while increasing overall food production, optimising fertilisers and other inputs for increased food production, and reducing food waste; and 2. how to transition to low-carbon alternatives i.e., adopting new low GHG options to meet new energy demand, replacing old fossil fuel sources with renewable form of energy, and concerning food production or consumption, it means substituting carbon-intensive products with options with a lower carbon footprint.

4.1 Energy Transition – vision for a fossil free future

The path to net-zero

Reaching net-zero emissions in energy consumption requires innovation across multiple sectors. Rockström and Gaffney, along with many fellow scientists, argue that the graphs depicting the different pathways towards net-zero by 2050 show clearly that in order to stabilise the planet's temperature under +1.5°C (compared to pre-industrial times), the lion's share of climate-action needs to be accomplished promptly. To achieve this, Rockström and Gaffney introduced a new rule of thumb which has been called the "Carbon Law" which consist of halving emission every decade from now till 2050 (Fig 2). The latter can and should be the guiding principle for initiating change across all levels of society, from the individual to the global.

The 2018 IPCC report[5] aligns closely with the carbon law, asserting that achieving a net-zero total CO2 emission by 2050 necessitates a reduction of global net anthropogenic CO2 emissions to fall by approximately 45% of 2010 levels by 2030 (within a range of 40–60%), culminating in a net-zero status by 2050[6].

The objective stands distinctly before everyone's eyes. Yet, the question remains: How will we attain it?

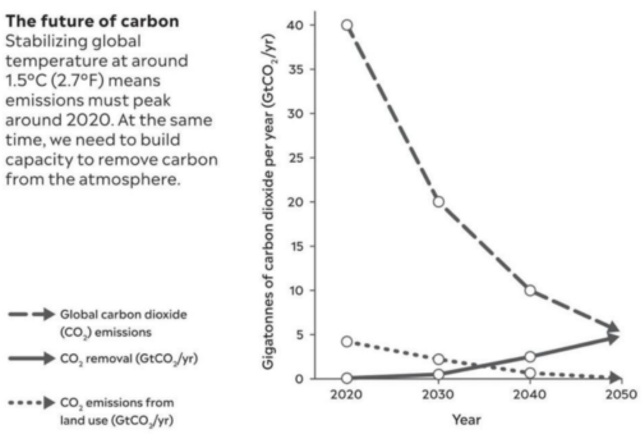


Fig 2. The future of carbon – stabilizing global temperatures at around 1.5°C[7]

[5] IPCC SR1.5 2018 report
[6] IPCC SR1.5 2018 report
[7] Figure from: Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House p. 125

To achieve this goal, it is evident that we have entered the initial stages of the endgame for fossil fuels. To effectively execute the necessary energy transition within the required timeframe, active participation in emission reduction is imperative across all sectors of the economy. Furthermore, where feasible, these sectors should also engage in GHG removal efforts.

The task at hand is of such magnitude that a clear vision or strategy must provide the guide needed to take us to net-zero by 2050. A robust strategy is essential, outlining the precise contributions from each sector, detailing the necessary policy adaptations, identifying readily deployable technologies, and distinguishing those that require additional research. Moreover, it should specify the timeline for scalability, leaving no room for ambiguity.

Many qualified institutions have proposed net-zero roadmaps that are all advocating for GHG reduction pathways that align with the objectives and prescriptions outlined by the carbon law, that is, halving GHG emissions every decade until 2050. We have opted to showcase the Net Zero roadmap (NZE) put forth by the International Energy Agency's (IEA), illustrating the progression towards 2030, 2040, and ultimately 2050. While multiple pathways exist to attain global net-zero emissions by 2050, numerous uncertainties have the potential to impact all of these roadmaps. Meaning that the IEA's NZE is one of many possible paths, not "the one and only path" to net-zero emissions, and update will be needed along the way as circumstances change. (Fig 3).

The IEA methodology used to present the NZE scenarios:

1. The Stated Policies Scenario (STEPS), which reflects all of today's announced policy intentions and targets, insofar as they are backed up by detailed measures for their realisation.

2. The Sustainable Development Scenario (SDS) supposes a certain surge in clean energy policies and investment which will put the energy system on track to achieve sustainable energy objectives in full, including the Paris Agreement, energy access and air quality goals. The SDS would guide certain committed countries toward achieving net-zero emissions by 2050, which would then inspire the world as a whole to reach the same goal, albeit by 2070.

3. The Net Zero Emissions by 2050 case (NZE2050), which extends the SDS scenario by modelling what would be needed in the next ten years to put global CO2 emissions on track for net zero by 2050. NZE2050 examines what it would take to get the entire world to net-zero by mid-century.

As you can observe in Fig 3, each scenario requires the GHG emission cuts to be increased further than the previous, and only the NZE2050 will allow the entire world to achieve net-zero by 2050.[8]

[8] IEA, WEO 2020

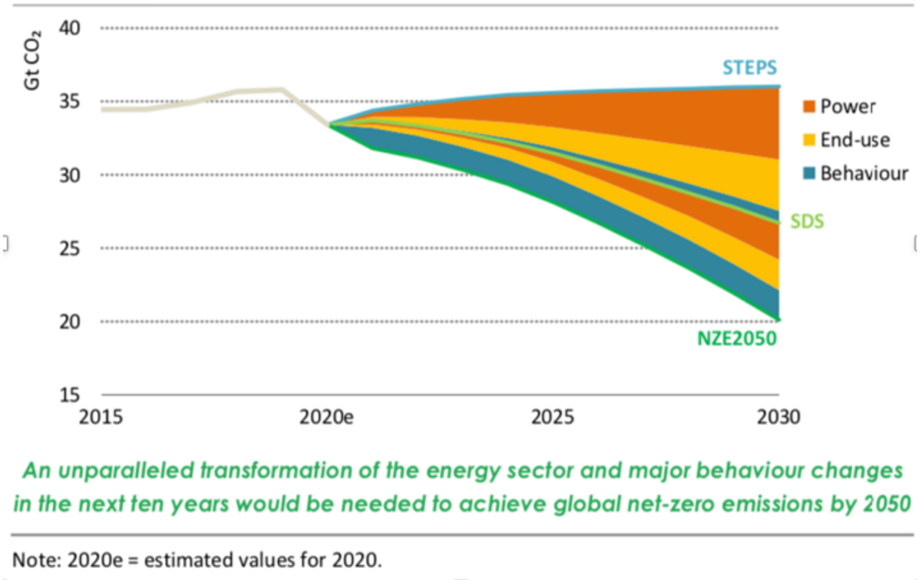


Fig 3: Energy and industrial process CO2 emissions and reduction levels in the scenarios

According to the IEA NZE roadmap, CO2 emissions from global energy-related and industrial process will fall to around 21 Gt CO2 in 2030 and to net-zero in 2050 (Fig 4). While some countries will reach net-zero before others, it is expected that overall CO2 emissions in advanced economies will fall to net-zero by around 2045 while emerging market and developing economies will fall to net-zero by 2050.

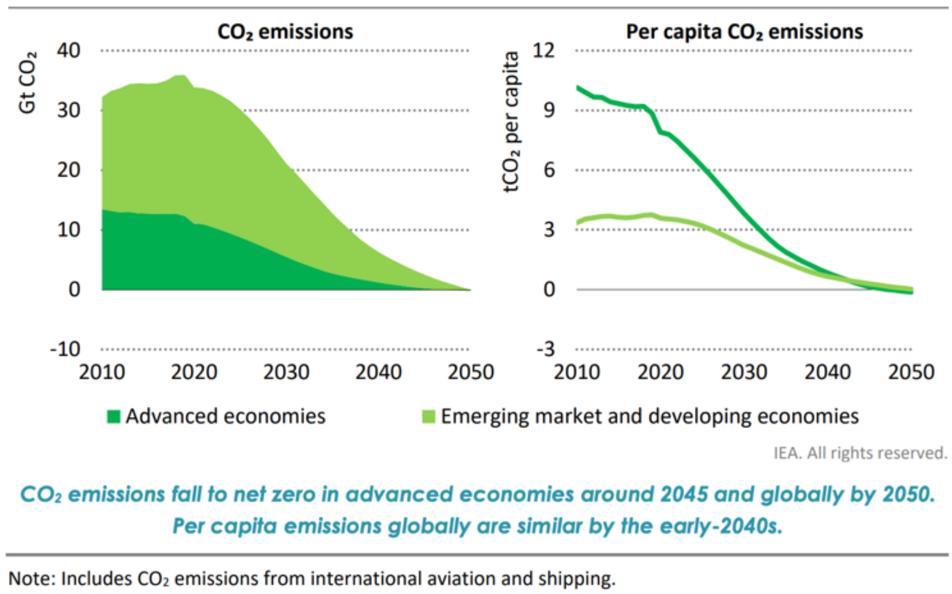


Fig 4: IEA CO2 emissions reductions from global energy-related and industrial process based on NZE roadmap[9]

Trends for the future

The transition to net-zero CO2 emissions requires a radical transformation of the energy sector. Innovative technologies, modern fuels and behavioural changes will all contribute significantly towards the cumulative CO2 savings needed. The key pillars of decarbonisation of the global energy system are energy efficiency, behavioural changes, electrification, renewables, hydrogen and hydrogen-based fuels, bioenergy and CCUS (Fig 5).

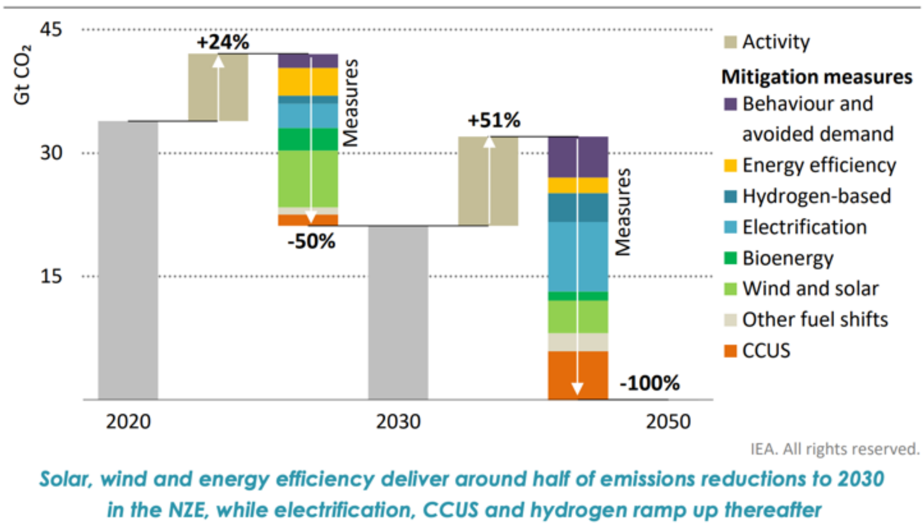


Fig 5: Emissions reductions by mitigation measure in the NZE, 2020-2050

To understand the potential of the technologies and fuels that will drive the transition across various sectors, it is crucial to have a clear understanding of these key concepts:

Energy efficiency

Energy efficiency means using less energy to perform the same task. Energy efficiency offers several benefits, including decreased energy demand, resulting in lower energy bills and reduced GHG emissions. While renewable energy technologies also help accomplish these objectives, improving energy efficiency is usually the cheapest way to reduce the use of fossil fuels. Examples include choosing LED light bulbs and energy efficient appliances or larger efforts such as upgrading insulation of private homes or choosing energy efficient vehicles.

According to the IEA NTZ roadmap, reducing energy demand growth through improvements in energy efficiency will make a significant contribution in reaching GHG emission targets for 2030 and 2050, while also resulting in substantial cost reductions. Numerous efficiency measures within industry, buildings, appliances, and transportation can be swiftly implemented and rapidly scaled up.

Renewables

Renewable energy is derived from resources that are replenished naturally on a human timescale. Such resources include biomass, geothermal heat, sunlight, water, and wind. All these sources have their strengths and weaknesses, and the choice depends on local availability. One of the main obstacles to the use of renewable sources is that many of them only produce electricity intermittently i.e., when the sun is shining, or the wind is blowing. However, they can be paired with energy storage solutions to provide reliable electricity 24 hours a day throughout the year.

Renewable energy technologies are the key to reducing emissions from electricity supply. While hydropower has been a leading low-emission source for many decades, it is mainly the expansion of wind and solar that is expected to lead the way to net-zero. According to the IEA NZE roadmap, the share of renewables in total electricity generation globally is expected to increase from 29% in 2020 to over 60% in 2030 and to nearly 90% in 2050 (Fig 6). Renewables are not only expected to play an important role in electricity generation but are also expected to play an important role in reducing emissions in buildings, industry and transport. Renewables can be used either indirectly, via the consumption of electricity or district heating that was produced by renewables, or directly, mainly to produce heat.

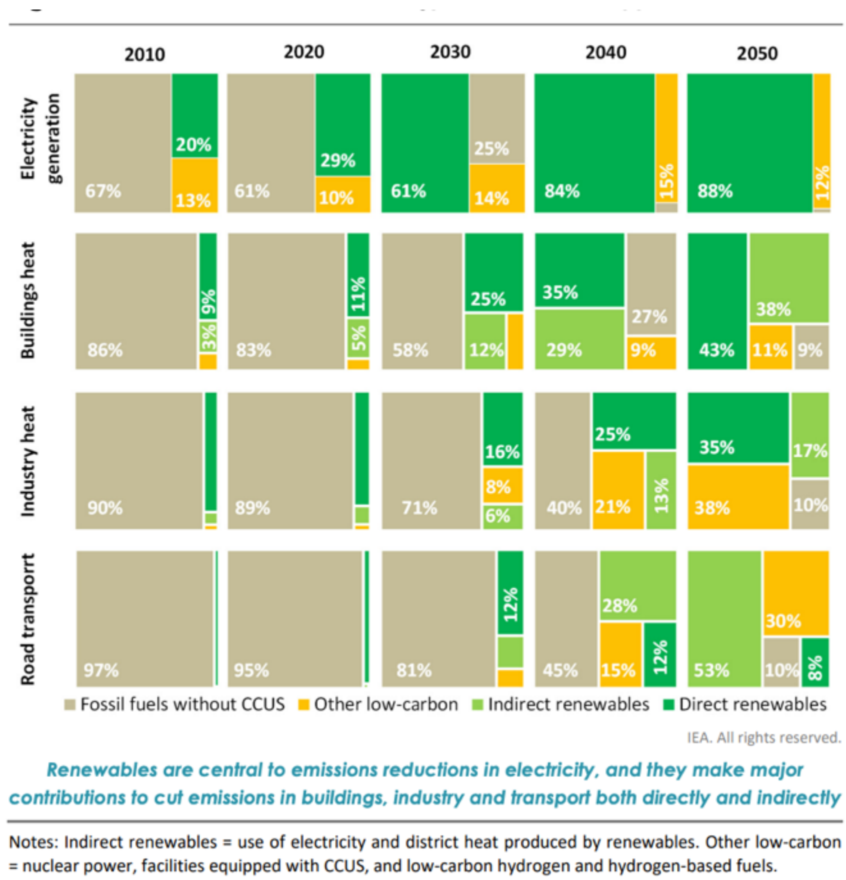


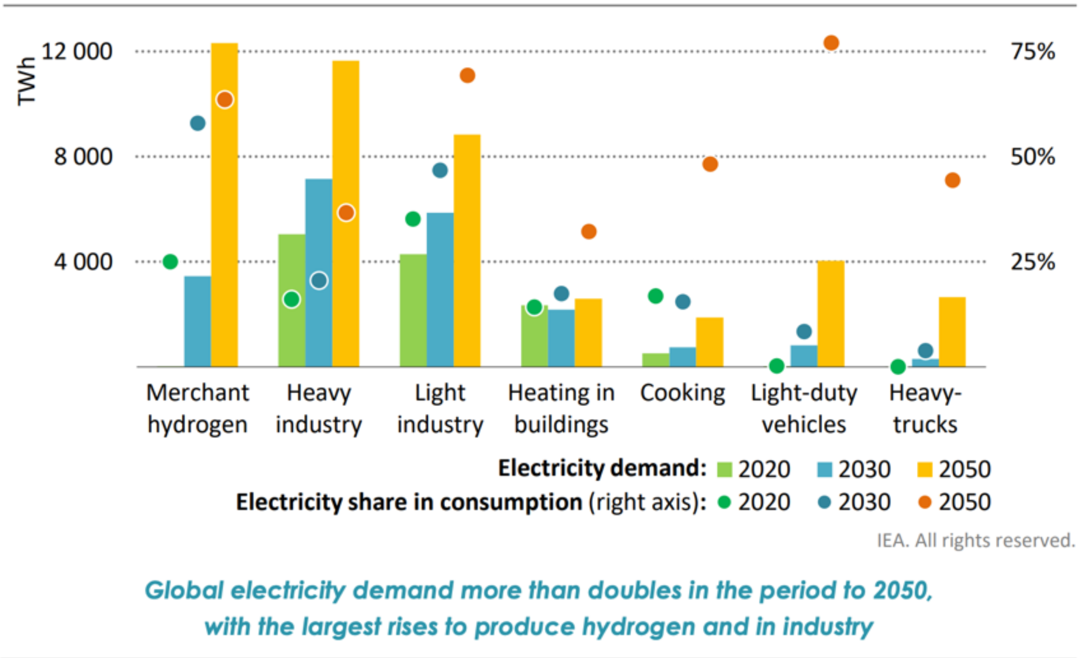
Fig 6: Fuel shares in total energy use in selected applications

Electrification

Electrification refers to the process of replacing technologies that use fossil fuels (coal, oil, and natural gas) with technologies that use electricity as the source of energy. Electrification has the potential to reduce GHG emissions depending on the resources used for electricity generation. For example, driving an electric vehicle (EV) powered by electricity generated from renewable sources can be more environmentally friendly than using a vehicle with a combustion engine that runs on diesel or petrol.

Based on the IEA NZE roadmap, electrification stands out as a critical catalyst for emissions reduction across various sectors in the next 30 years. It is projected to contribute to approximately 20% of the total emissions reduction target by 2050. Despite significant electricity "savings" resulting from energy efficiency, global electricity demand is expected to more than double between 2020 and

2050 due to electrification[10], with substantial increase in demand from industry, hydrogen production and passenger cars. (Fig 7)



Notes: Merchant hydrogen = hydrogen produced by one company to sell to others. Light-duty vehicles = passenger cars and vans. Heavy trucks = medium-freight trucks and heavy-freight trucks.

Fig 7: Global electricity demand and share of electricity in energy consumption in selected sectors[11]

Storage

Energy storage involves capturing energy produced at one point in time for subsequent utilisation and its fundamental purpose lies in balancing energy demand with energy production. Energy, depending on its form, can be stored in several ways. Water reservoirs formed by constructing dams serve as a form of energy storage, allowing the generation of electricity at a later time. Electricity cannot itself be stored on any scale, but it can be converted to other forms of energy which can be stored and later reconverted to electricity on demand. Storage systems for electricity include batteries, ultra-capacitors and pumped hydro-storage. Gas such as natural gas, biogas, biomethane or hydrogen can be stored on a large scale in underground storage (usually depleted gas reservoirs, aquifers, and salt caverns) or as liquefied natural gas (LNG). As it is easier to store large amount of gas, increased research and experimentation is done to convert power to gas and as such store the energy as a fuel. Liquid energy like crude and refined oil and finished oil products are usually stored in tanks above the ground.

As we have seen, renewable energy sources are critical to the decarbonisation of our electricity systems, but most (except biogas) are by their nature intermittent. Incorporating energy storage systems between renewable generation and consumption enables the balance of demand and supply. As a result, it becomes an indispensable component for facilitating the maximum integration of renewable energy into the energy mix. Research and innovation are still needed to reach sufficient storage capacity to meet expected demand for energy storage in 2050.

[10] with electricity produced from renewable and not from fossil fuels
[11] IEA,2021, Net Zero by 2050 – A Roadmap for the Global Energy Sector

Hydrogen and hydrogen-based fuels

Hydrogen can be produced from a variety of sources, either from natural gas and coal or through the electrolysis of water using renewable power like solar and wind. The GHG emissions from hydrogen depend on the source of its production. This distinction gives rise to terms like 'grey', 'blue' and 'green' hydrogen. 'Grey' hydrogen is derived from fossil fuels and often associated with higher emissions. 'Blue' hydrogen also comes from fossil fuels, but it incorporates a process to capture and store the CO2 emissions, making it a more CO2-friendly option. On the other hand, 'green' hydrogen is obtained through water electrolysis in specialised electrochemical cells powered by electricity generated from renewable sources and is CO2 neutral.

Hydrogen is easy to store and transport, making it an excellent backup fuel for intermittent renewables in the medium and long term. However, its integration into the established natural gas infrastructure will necessitate some infrastructure upgrading and retrofitting. While less than 0.1% of global dedicated hydrogen production today comes from water electrolysis, with declining costs for renewable electricity, in particular from solar PV and wind, there is growing interest in electrolytic hydrogen. Green hydrogen can, if properly developed over the coming years, play an important role in the decarbonisation of certain sectors, especially the chemical industries and other energy-intensive industries such as steel and cement, aviation and maritime and land transport.

Bioenergy

Bioenergy is a type of renewable energy derived from living organic materials called biomass. This resource can be utilised to produce transportation fuels, heat, electricity, and various products. Biomass is derived from plant and algae-based materials including crop waste, forest residues, purpose grown grasses, microalgae, and food waste. Biomass can be converted into liquid transportation fuels (called biofuels, the two most common being ethanol and biodiesel) that are equivalent to fossil-based fuels, such as gasoline, jet, and diesel fuel. Biomass can also be converted into heat and electricity using biopower technologies. There are three ways to harvest the energy stored in biomass to produce biopower: burning, bacterial decay, and conversion to a gas or liquid fuel. Finally, biomass can also serve as a renewable alternative to fossil fuels in the manufacturing of bioproducts such as plastics, lubricants, industrial chemicals, and many other products currently derived from petroleum or natural gas.

One of the key advantages of bioenergy is that it can use existing infrastructure, i.e., biomethane can be used in existing natural gas pipelines and end-user equipment, while many liquid biofuels can use existing oil distribution networks and be used in vehicles with only minor or limited alterations. For bioenergy to be carbon neutral it is important to complement it with carbon capture and storage.

In the IEA NZE roadmap bioenergy with carbon capture and storage (BECCS) plays a critical role in offsetting emissions from sectors where the full elimination of emissions is otherwise very difficult to achieve.

Carbon Capture and Storage, Carbon Capture and Utilization

Carbon capture and storage (CCS), also known as carbon capture and sequestration, involves capturing CO2 before it is released into the atmosphere and then permanently storing it (carbon sequestration), often within underground geological formations. The aim of CCS is to prevent the release of CO2 with the intent to mitigate the effects of climate change.

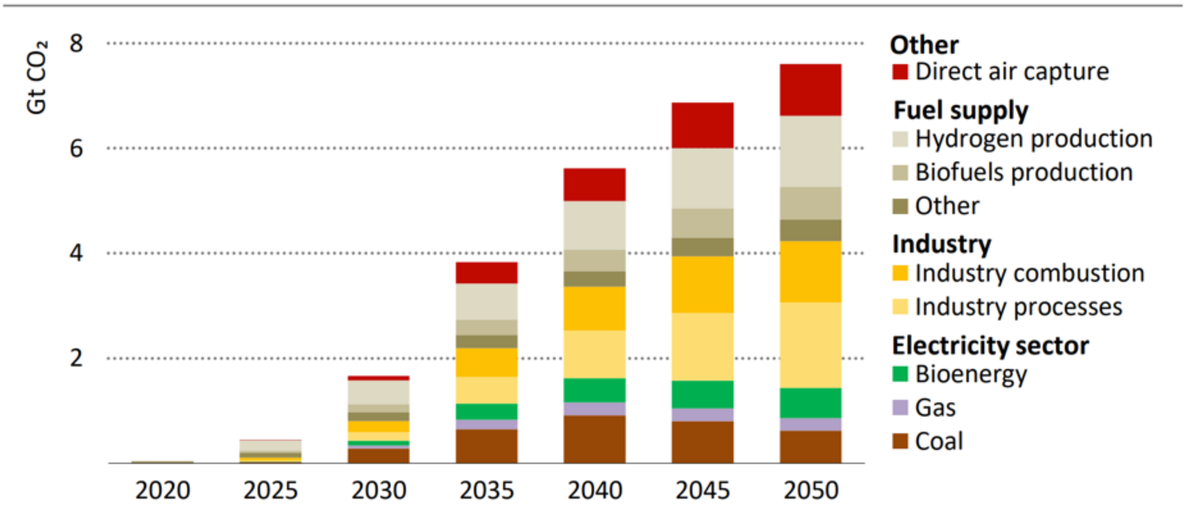
Carbon capture and utilization (CCU) is the process of capturing CO2 to be recycled for further usage. CCU differs from CCS in that it does not aim nor result in permanent geological storage of CO2.

Instead, CCU aims to convert the captured CO2 into more valuable substances or products, such as plastics, concrete or biofuel, while retaining the carbon neutrality of the production processes.

CCU and CCS are sometimes discussed collectively as carbon capture, utilization, and sequestration (CCUS). Because CCS is a relatively expensive process yielding a product with an intrinsic low value (i.e., CO2), hence, carbon capture makes more sense economically when being combined with a utilization process where the cheap CO2 can be used to produce high-value products to offset the high costs of capture operations.

Certain specific locations with a very large potential for producing renewables-based electricity and bioenergy may become a key source of carbon dioxide removal (CDR). This includes making use of renewable electricity sources to produce large quantities of biofuels with CCUS, and to carry out direct air capture with carbon capture and storage (DACCS). An example of such places includes Iceland where we find the Orca Climeworks CDR plant.

According to the IEA NZE roadmap, CCUS can facilitate the transition to net-zero CO2 emissions in a number of ways including: tackling emissions from existing assets, providing a way to address emissions from some of the most challenging sectors, providing a cost-effective pathway to scale up low-carbon hydrogen production rapidly, and allowing for CO2 removal from the atmosphere through BECCS and DACCS (Fig 8).



By 2050, 7.6 Gt of CO_2 is captured per year from a diverse range of sources. A total of 2.4 Gt CO_2 is captured from bioenergy use and DAC, of which 1.9 Gt CO_2 is permanently stored.

Fig 8: Global CO2 capture by source in NZE

Behavioural change

The scale of the energy sector transformation can only be achieved with the active and willing participation of citizens. It is ultimately people who drive demand for energy-related goods and services, and societal norms and personal choices will play a central role in steering the energy system onto a sustainable path.

In the IEA NZE roadmap 55% of emissions reductions require both the deployment of low-carbon technologies and the active engagement of consumers, e.g., installing a solar water heater or buying an EV. Another 8% of emissions reductions however stem directly and exclusively from behavioural changes and materials efficiency gains that reduce energy demand, e.g., the decision to fly less or changing to a low-carbon diet. Consumer attitudes can also impact investment decisions by businesses concerned about public image.

Energy Sector Pathways to Net-Zero

The roadmap provided by the IEA NZE states that up to 2030, about half of emissions savings will result from energy efficiency, wind, and solar sources. These sources will also continue to drive emissions reductions beyond 2030. Looking toward 2050, the trend shifts to increased electrification, utilization of hydrogen with carbon capture, and the deployment of CCUS technology. It is important to note that most of these technologies are not yet sufficiently mature, but with continued research and innovation are projected to contribute to over half of the emissions savings between 2030 and 2050.[12]. The IEA NZE taps into all opportunities to decarbonise the energy sector, across all fuels and all technologies (Fig 9).

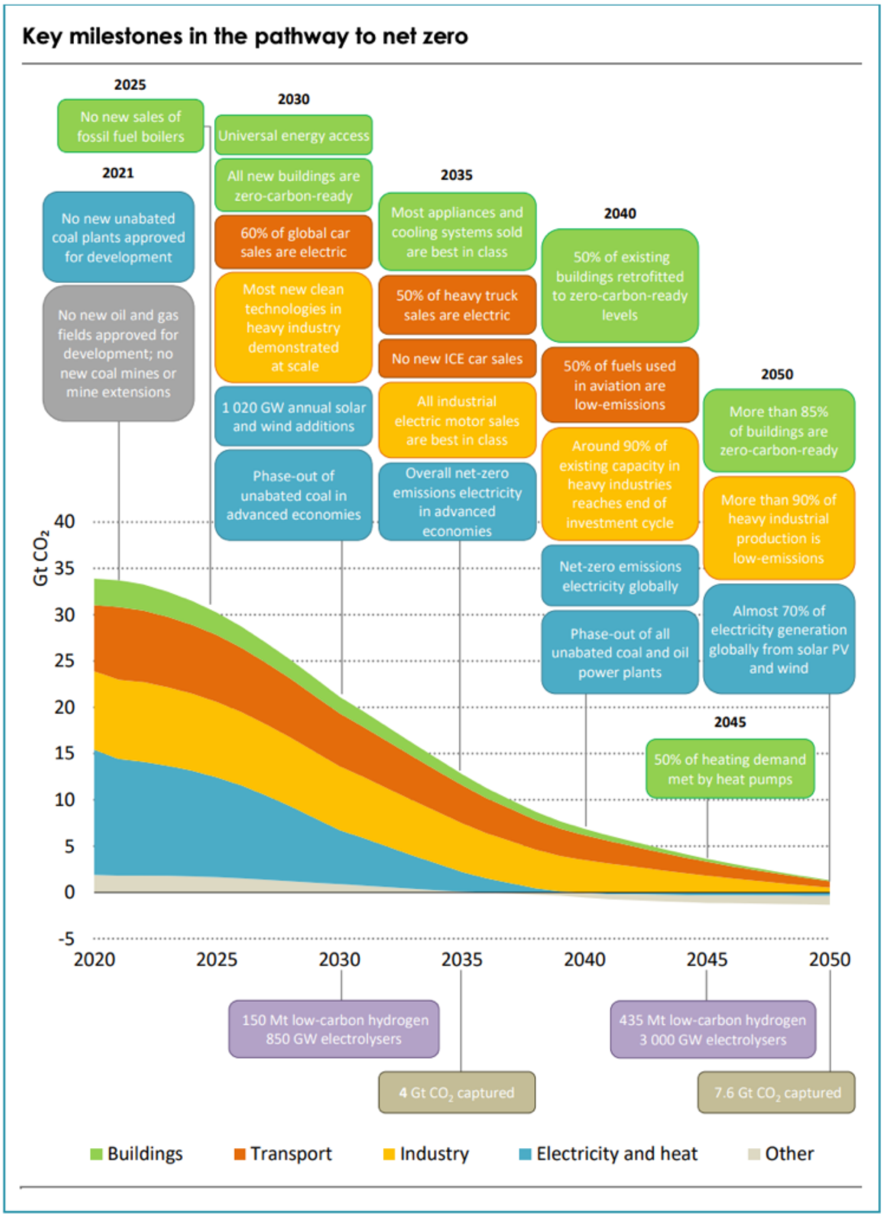


Fig 9: IEA Net-Zero roadmap[13]

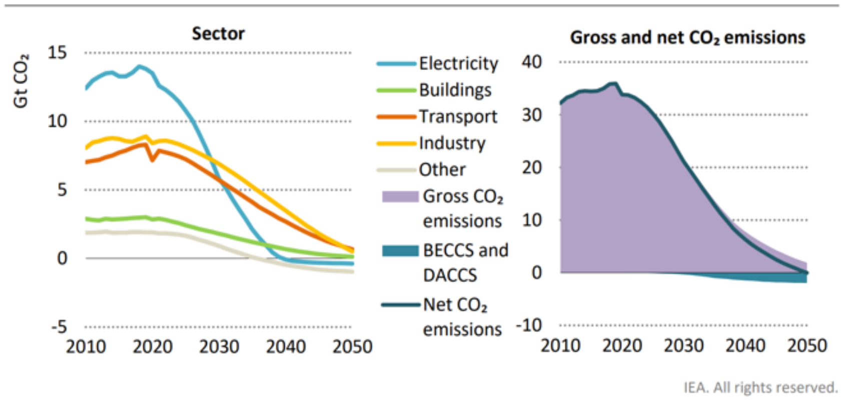
[12] IEA, 2021, Net Zero by 2050 – A Roadmap for the Global Energy Sector
[13] Further explore the IEA interactive visual Net-zero roadmap online: https://www.iea.org/reports/net-zero-by-2050

Let's dig a little deeper into the various sectors:

The fastest and largest reductions in global emissions will initially be observed in the electricity sector (Figure 10). Electricity generation was the largest source of emissions in 2020, but emissions will drop by nearly 60% in the period to 2030, mainly due to major reductions from coal-fired power plants, with the electricity sector eventually becoming a small negative source of emissions around 2040.

In parallel, emissions from the buildings sector will fall by 40% between 2020 and 2030 thanks to a shift away from the use of fossil fuel boilers (natural gas boilers) and the retrofitting[14] of existing building stock to improve its energy performances.

And finally, emissions from industry and transport are both expected to fall by around 20% over this period, while their pace of emissions reductions is expected to accelerate during the 2030s as the roll-out of low-emissions fuels and other emissions reduction options is scaled up. Nonetheless, there are a number of areas in transport and industry in which it will be difficult to eliminate emissions entirely, such as aviation and heavy industry, and both sectors are therefore expected to have a small level of residual emissions in 2050. These residual emissions are offset with applications of BECCS and DACCS.



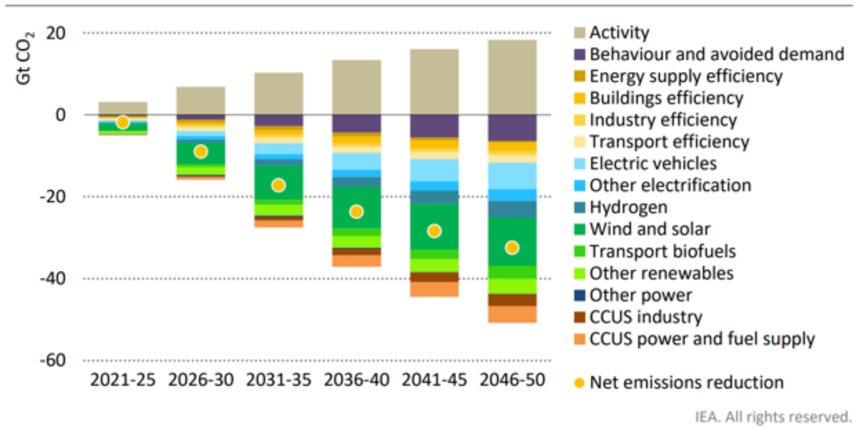
Emissions from electricity fall fastest, with declines in industry and transport accelerating in the 2030s. Around 1.9 Gt CO_2 are removed in 2050 via BECCS and DACCS.

Notes: Other = agriculture, fuel production, transformation and related process emissions, and direct air capture. BECCS = bioenergy with carbon capture and storage; DACCS = direct air capture with carbon capture and storage. BECCS and DACCS includes CO_2 emissions captured and permanently stored.

Fig 10: IEA, Global net-CO2 emissions by sector, and gross and net CO2 emissions in the NZE[15]

The rapid deployment of more energy-efficient technologies, electrification of end-uses and swift growth of renewables are all expected to play a central part in emissions reductions throughout the period 2020 - 2050 (Fig 11). By 2050, it is expected that nearly 90% of all electricity generation is from renewables. There is also a major role for emerging fuels and technologies, notably hydrogen and hydrogen-based fuels, bioenergy and CCUS, especially in sectors where emissions are often most challenging to reduce (Fig 10).

[14] Retrofitting building involves upgrading its energy-consuming systems. Retrofitting may include improving or replacing lighting fixtures, ventilation and heating systems as well as windows and doors and adding insulation where it makes economic sense.
[15] IEA, 2021, Net Zero by 2050 – A Roadmap for the Global Energy Sector

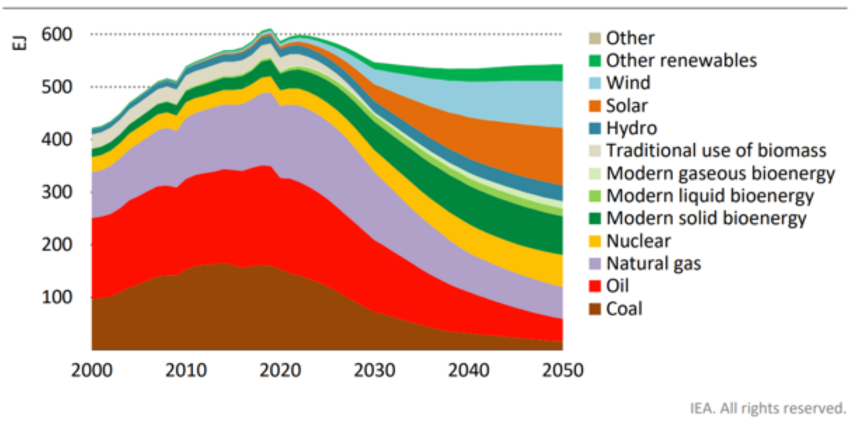


Renewables and electrification make the largest contribution to emissions reductions, but a wide range of measures and technologies are needed to achieve net-zero emissions

Notes: Activity = changes in energy service demand from economic and population growth. Behaviour = change in energy service demand from user decisions, e.g. changing heating temperatures. Avoided demand = change in energy service demand from technology developments, e.g. digitalisation.

Fig 11: Average annual CO2 reductions from 2020 in the NZE[16]

According to the IEA NZE total energy supply will fall 7% from 2020 to 2030 and remain relatively stable after that up till 2050. Increased energy intensity (the amount of energy used to generate a unit of GDP), achieved through electrification, energy efficiency and behavioural changes, is improved over this period and off-sets increased energy demand caused by population and economic growth (Fig 12).

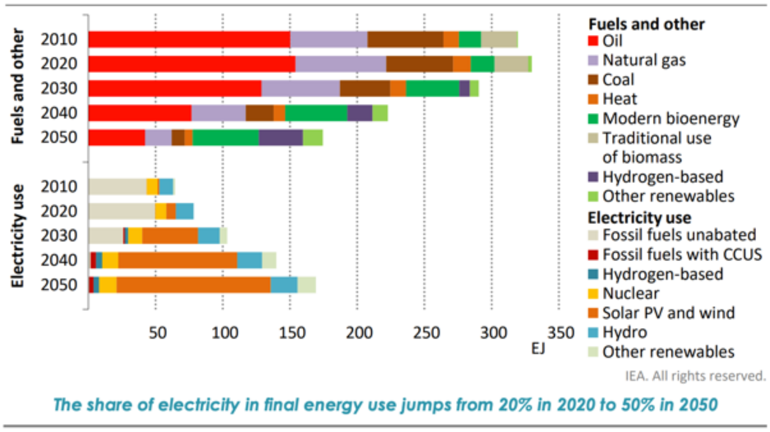


Renewables and nuclear power displace most fossil fuel use in the NZE, and the share of fossil fuels falls from 80% in 2020 to just over 20% in 2050

Fig 12: Total energy supply of unabated fossil fuels and low-emissions energy sources[17]

The energy mix in 2050 is expected to be very different and much more diverse than today, with a massive reduction in fossil fuels and a massive increase in renewables (Fig 12 and 13). Some amount of fossil fuels is still expected to be used in 2050 in producing non-energy goods (chemical feedstocks, lubricants, paraffin waxes and asphalt) in plants with CCUS, and in sectors where emissions are especially hard to abate such as heavy industry and long-distance transport. However, all remaining emissions in 2050 are expected to be offset by negative emissions elsewhere.

[16] IEA, 2021, Net Zero by 2050 – A Roadmap for the Global Energy Sector
[17] IEA, 2021, Net Zero by 2050 – A Roadmap for the Global Energy Sector



Note: Hydrogen-based includes hydrogen, ammonia and synthetic fuels.

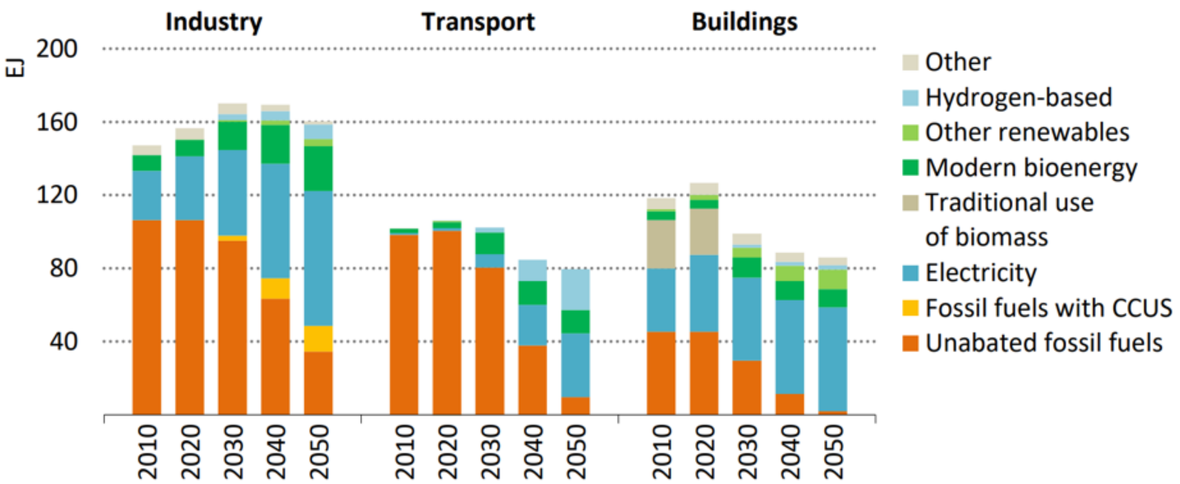
Fig 13. Global total final consumption by fuel in the NZE[18]

The energy intensive heavy industries including steel, cement, plastics, aluminium and chemicals are growing substantially in the coming years due to the growth of both population and the middle-class. Most of the global emissions reductions from industry in the NZE during the period to 2030 are delivered through energy and materials efficiency improvements, electrification of heat, and fuel switching to solar thermal, geothermal and bioenergy. In the following years, CCUS and hydrogen play an increasingly important role in reducing CO2 emissions, especially in heavy industries such as steel, cement and chemicals. Electricity consumption in industry more than doubles between 2020 and 2050, providing 45% of total industrial energy needs in 2050.

In transport, there is a rapid transition away from oil worldwide, which provided more than 90% of fuel use in 2020. In road transport, electricity comes to dominate the sector, providing more than 60% of energy use in 2050, while hydrogen and hydrogen-based fuels play a smaller role, mainly in fuelling long-haul heavy-duty trucks. In shipping, energy efficiency improvements significantly reduce energy needs (especially up to 2030), while advanced biofuels and hydrogen-based fuels increasingly displace oil. In aviation, the use of synthetic liquids and advanced biofuels grows rapidly, and their share of total energy demand rises from almost zero today to almost 80% in 2050. Overall, electricity is expected to be the dominant fuel in the transport sector globally by the early 2040s, and to account for around 45% of energy consumption in the sector in 2050 (compared with 1.5% in 2020). Hydrogen and hydrogen-based fuels account for nearly 30% of consumption (almost zero in 2020) and bioenergy for a further 15% (around 4% in 2020).

In the context of buildings, the shift towards electrification of end-uses, including heating, results in a projected increase in demand for electricity by approximately 35% from 2020 to 2050. Consequently, electricity emerges as the primary fuel source by 2050, accounting for two-thirds of the total energy consumption within the buildings sector. Overall energy consumption in the buildings sector contracts by around 15% between 2030 and 2050 given continued efficiency improvements and electrification. By 2050, energy use in buildings is 35% lower than in 2020. Energy efficiency measures – including improving building insulation and ensuring that all new appliances brought to market are the most efficient models available play a key role in limiting the rise in electricity demand. Without these measures, electricity demand in buildings would be around 70% higher in 2050.

[18] IEA, 2021, Net Zero by 2050 – A Roadmap for the Global Energy Sector



There is a wholesale shift away from unabated fossil fuel use to electricity, renewables, hydrogen and hydrogen-based fuels, modern bioenergy and CCUS in end-use sectors

Note: Hydrogen-based includes hydrogen, ammonia and synthetic fuels.

Fig 14: Global final energy consumption by sector and fuel[19]

Furthermore, household's energy consumption is expected to fall by 25% between 2020 and 2030, largely as a result of a major push to improve efficiency and to phase out the traditional use of solid biomass for cooking which is replaced by liquefied petroleum gas (LPG), biogas, electric cookers and improved bioenergy stoves. Universal access to electricity is achieved by 2030, and this adds less than 1% to global electricity demand in 2030.

4.2 Food Transition – vision for a planetary health diet

Emissions and footprint of food production

While the vast majority of GHG emissions come from the energy sector, the battle for climate change is not only being fought over the global energy system. Decarbonisation is also urgently needed in the production of food. Both transitions are needed to succeed; that is undeniable. But right now, the energy transformation – despite all our concerns, the frustratingly slow progress, and the lack of urgency – is far ahead of food. The food transition is lagging in terms of policy, economy, awareness and technology …. The topic of sustainable food is today …. where the energy agenda was 30 years ago[20].

The primary driver behind our breach of the most critical planetary boundaries, such as those related to land biodiversity, climate, and nutrients, is food production. This trend poses a significant threat to the stability and resilience of our planet. Without serious attention, we face multiple crises. Lifting 1 billion people out of poverty and hunger and feeding another 2 to 3 billion new citizens by 2050 will require some 50% more food[21]. Considering we are already in trouble today, the scenario in 2050 looks far from promising.

[19] IEA, 2021, Net Zero by 2050 – A Roadmap for the Global Energy Sector
[20] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House
[21] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House

The production of food is responsible for approximately one quarter of CO2 emissions and 56% of the remaining GHGs (methane, nitrous oxide and ground level ozone), hence its overall contribution to climate change is significant[22]. A new approach is urgently needed to halt the degradation of land and to transform agriculture from a source of CO2 emissions to a “carbon sink” taking up carbon from the atmosphere and storing it below the ground and in vegetation.

Use of Earth’s precious surface

For most of humanity’s history on Earth, we have existed as hunter-gatherers, and the majority of the land remained wild, characterised by landscapes dominated by forests, meadows, and shrubbery. Landscapes have undergone significant changes over the past few centuries, with wild habitats giving way to agricultural land through conversion that alters the land from its original state. Dramatic increases in population, especially since the industrial revolution, has increased the need for food and fodder production at the expense of forests and natural grasslands.

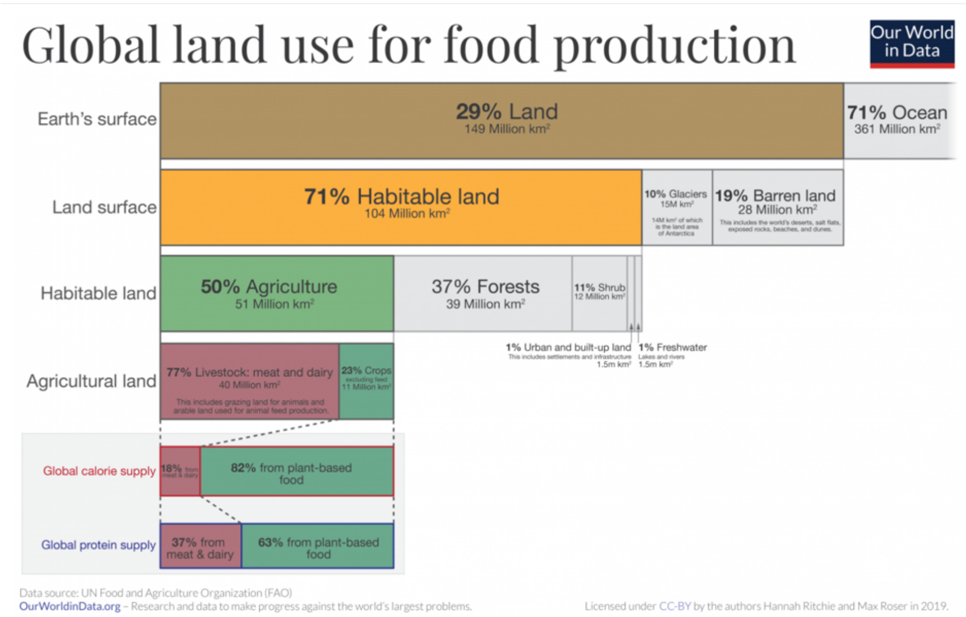


Fig 15: Global land use for food production, UN Food and Agriculture Organisations (FAO)

According to the Food and Agricultural Organisation (FAO) (Fig 15) 29% of Earth’s surface is land, of which 10% is glaciers and 19% is barren land including deserts, dry salt flats, beaches, sand dunes, and exposed rocks, leaving 71% as habitable land. Of the habitable land, it is estimated that today, 50% is used for agriculture, 37% is forests, 11% shrubs and grasslands, 1% as freshwater coverage and only 1%[23], a much smaller share than many suspect, is built-up urban area which includes cities, towns, villages, roads and other human infrastructure[24].

Of the 50% of land used for agriculture there is a highly unequal distribution of land use between livestock and crops for human consumption. If we combine pastures used for grazing with land used to grow crops for animal feed, livestock accounts for 77% of global farming land. While livestock takes up most of the world’s agricultural land it only produces 18% of the world’s calories and 37% of total protein[25].

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[22] Rockström, J. Bignet, V., Landqvist M., Stordalen G., The World-Changing Cookbook, Max Stroem
[23] Note that estimates of the global urban land reported in the literature vary widely from less than 1–3 % primarily because different definitions of urban land were used, but is in any case a relatively small number.
[24] Hannah Ritchie and Max Roser, 2020. Environmental impacts of food production, Our World in data
[25] Hannah Ritchie and Max Roser, 2020. Environmental impacts of food production, Our World in data

As a result of the scope and scale of food production, it is the single largest reason that we have transgressed planetary boundaries. The food industry is the single largest sector in terms of climate impact, land use, biodiversity loss, damage to aquatic habitats, freshwater use, over-fertilisation and use of antibiotics and pesticides. Agriculture is the single largest threat to the stability of the planet and our life support systems, from fresh water, pollinators, and soil health to rainfall generation, and quality of air and water. Food production is putting our future at risk[26].

To achieve a sustainable environment, we need to put an immediate stop to land conversion and radically change how we produce food. If we are to feed 11 billion people in the future, we need to reduce our consumption of the most environmentally harmful foodstuffs, increase the agricultural output of the cultivated land and reduce food wastage.

Impact of various food groups and sectors

To be able to determine what actions are most effective it is important to understand what food groups have the biggest footprints, i.e., which foods use the highest percentage of land in their production processes, as well as understand what food groups have the biggest GHG emissions.

Looking at the footprint in terms of nutritional units is useful, as this indicates a measure of how low or high-impact different foods are in supplying protein or energy/calories. Fig 16 indicates the land footprint of foods, measured in square meters (m2) per 1000 kilocalories. As you can see, it is easy to observe some significant differences in the footprint especially between the top two (beef and lamb and mutton) and the rest of the food groups.

One example that is easy to relate to: one burger with fries requires more than seven times as much land area to produce than a plate of pasta with tomato sauce![27]

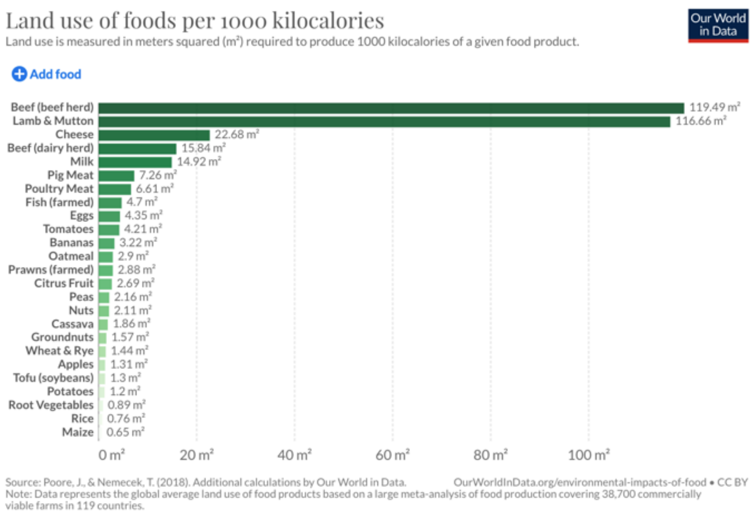

Fig 16: Land use of food per 1000 kilocalories[28]

Categories of GHG emissions from Food Production

While approximately three-quarters of global GHG emissions comes from the energy sector, one-quarter comes from the global food system, which encompasses four key categories worth considering when trying to quantify GHG emissions related to food production (Fig 17).

[26] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House
[27] Rockström, J. Bignet, V., Landqvist M., Stordalen G., 2018. The World-Changing Cookbook, Max Stroem
[28] Poore J., Memecek T., 2018. Land use of food per 1000 kilocalories. Our World in Data

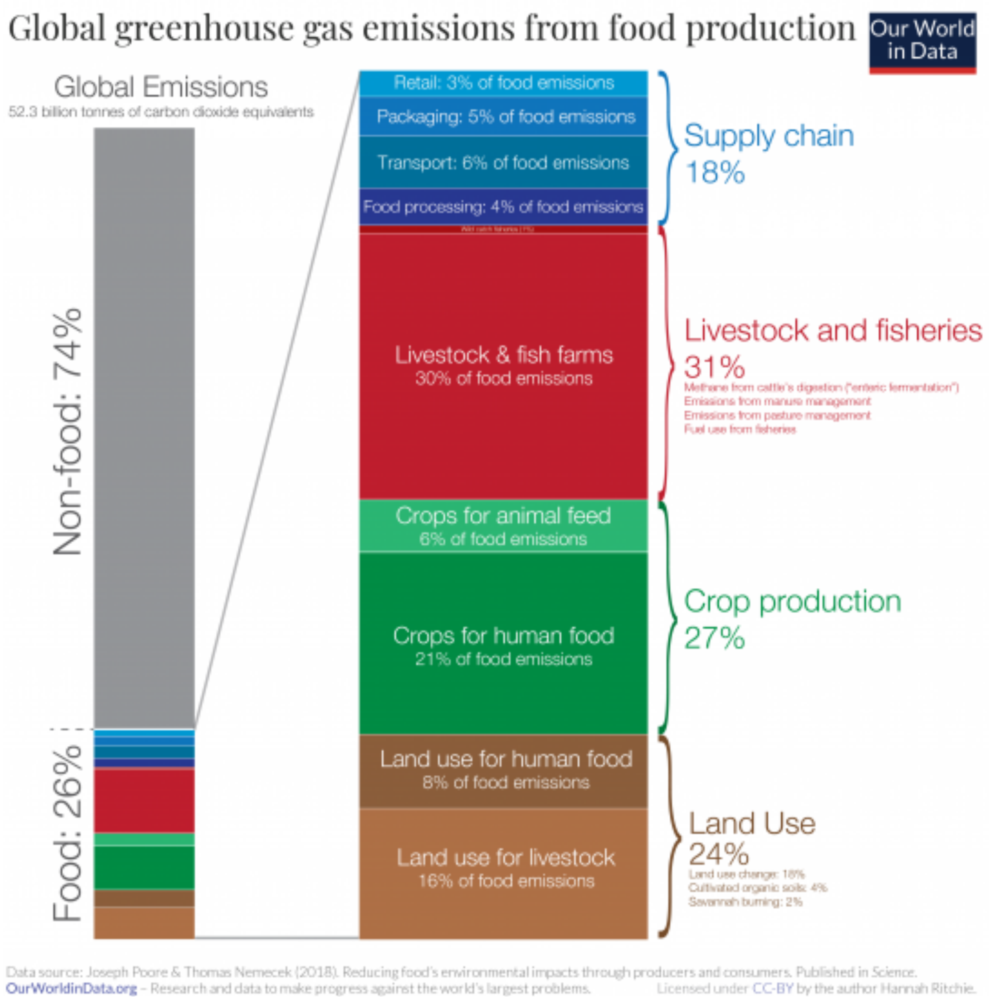

Fig 17. Global GHG emissions from food production[29]

Land use accounts for 24% of food emissions

Twice as many emissions result from land use for livestock (16%) as for land use for human food (8%). Land use is the result of conversion of forests, grasslands and other carbon 'sinks' into agricultural land or pasture resulting in CO2 emissions. 'Land use' here is the sum of land use change, savannah burning and organic soil cultivation (ploughing and overturning of soils).

Crop production accounts for 27% of food emissions.

21% of food's emissions comes from crop production for direct human consumption, and 6% comes from the production of animal feed. These are the direct emissions resulting from agricultural production, which include elements such as the release of nitrous oxide from the application of fertilizers and manure, methane emissions from rice production, and carbon dioxide from agricultural machinery.

Livestock & fisheries account for 31% of food emissions.

Livestock, including animals raised for meat, dairy, eggs and seafood production, contribute to emissions in several ways. Ruminant livestock, mainly cattle, produce methane through their digestive processes (a process known as 'enteric fermentation'). Manure management, pasture management, and fuel consumption from fishing vessels also fall into this category. This 31% of emissions relates to on-farm 'production' emissions only: it does not include land use change or supply chain emissions.

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[29] based on data from the meta-analysis by Joseph Poore and Thomas Nemecek (2018), published in Science

Supply chains account for 18% of food emissions.
Food processing (converting produce from the farm into final products), transport, packaging and retail all require energy and resource inputs. Many assume that eating local is key to a low-carbon diet, however, transport emissions are often a relatively small percentage of food's total emissions, at only 6% globally. While supply chain emissions might seem significant, accounting for 18%, they are essential if we want to abate emissions related to food waste. Food waste emissions are large: globally approximately one-quarter of food ends up as wastage either from supply chain losses or consumers. For this reason, a modern and more sustainable supply chain connoted by durable packaging, efficient refrigeration and improved food processing is pivotal to prevent food waste[30] (Fig 18).

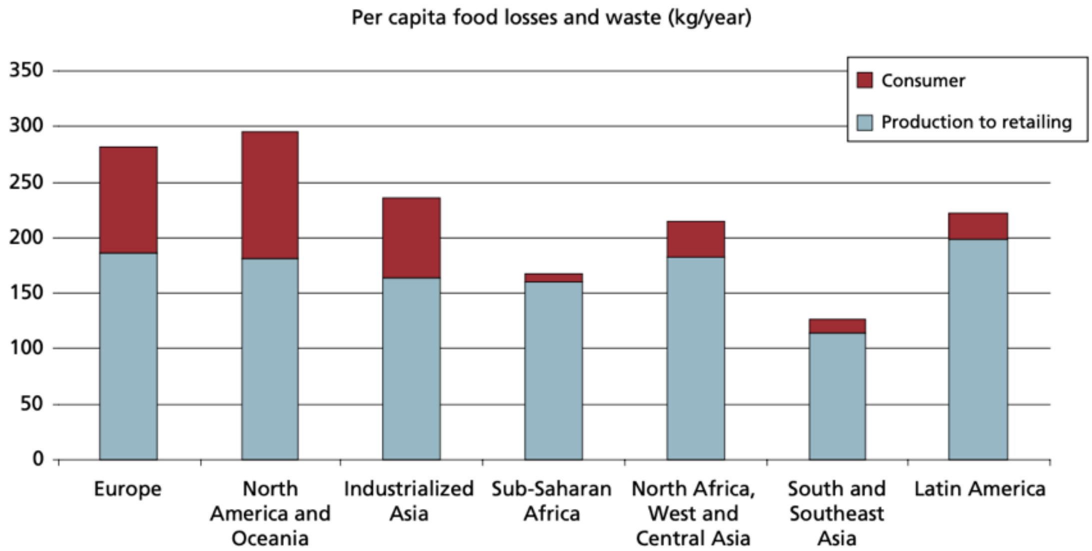

Fig 18: Per capita food losses and waste, at consumption and pre-consumptions stages, in different regions[31]

Unlike many aspects of energy production where viable opportunities for upscaling low-carbon energy and improving energy efficiency are available, the ways in which we can decarbonize agriculture are less clear. We need inputs such as fertilizers to meet growing food demands, and we can't stop cattle from producing methane. Just like with the energy sector transformation, there is no silver bullet solution to GHG emission from food production, rather, we will need a range of complementary solutions including changes to diets, food waste reduction, improvements in agricultural efficiency and technologies that make low-carbon food alternatives scalable and affordable.

Solutions – way forward for food productions

There is substantial scientific evidence that links diets with human health and environmental sustainability. Yet the absence of globally agreed scientific targets for healthy diets and sustainable food production has hindered large-scale and coordinated efforts to transform the global food system. The EAT-Lancet Commission has convened a group of leading scientists to try to fill this gap, tasked to synthesize our knowledge on healthy diets from sustainable food systems and to identify the safe boundaries for the health of both people and planet. The Commission has developed the first global scientific targets for healthy diets, called the planetary health diet, and sustainable food

[30] Gustavsson J., Cederberg C., Sonesson U., van Otterdijk R., Meybeck A., 2011. Global Food Losses and Food Waste - extent, causes and prevention, FAO
[31] Gustavsson J., Cederberg C., Sonesson U., van Otterdijk R., Meybeck A., 2011. Global Food Losses and Food Waste - extent, causes and prevention, FAO

production as a first attempt to set universal scientific targets for the food system that apply to all people and the planet[32].

The Commission acknowledges that food systems have environmental impacts along the entire supply chain from production to processing and retail. Furthermore, these impacts reach beyond human and environmental health, also affecting society, culture, economy, and animal health and welfare. Given the breadth and depth of each of these topics, the Commission decided to focus on two “end-points” of the global food system: final consumption (healthy diets) and production (sustainable food production). This choice is made because these two factors disproportionately impact human health and environmental sustainability.

Targets: Healthy Diet and Sustainable Food Production

It is crucial for the global food system to function within limits for human health and food production, as well as within the safe boundaries of Earth's system processes. Going beyond the thresholds of any Earth system process (for instance, high rates of biodiversity loss) or neglecting any essential food group (like insufficient vegetable intake) raises the potential for jeopardizing both Earth's stability and human health. The Commission has therefore identified two fundamental targets to deliver health for both people and planet, achieved through five strategies:

TARGET 1 – Healthy Diet

Food is putting our health at stake and shortening our lives. It is the single largest killer, responsible for more deaths than smoking, AIDS, tuberculosis, and terrorism combined. Three independent research studies in 2019 estimated that 11 million people in the world die prematurely because of unhealthy food. The fastest growing killers are obesity and diabetes[33]. Obesity is no longer exclusively a problem in wealthy countries, today more than 70% of the 2 billion overweight and obese individuals are in low and lower-middle income countries[34]. Furthermore, as economic affluence has increased in many emerging economies, many have adopted the “western style diet”, rich in animal source foods, refined grains, saturated fats and sugar, and low in healthy plant-based foods. This is a diet which is not only much higher in GHG emissions than traditional diets, but it is also linked to increased risk for certain types of “modern” preventable diseases (e.g., diabetes, cancer and heart disease) and as such not only an increased risk to the climate but also the overall health of people[35].

The EAT-Lancet Commission has defined scientifically quantitative targets for a healthy and sustainable diet within the operating spaces for all people, geographies and cultures around the world. This “planetary health diet” optimises health, defined broadly as being a state of complete physical, mental and social well-being and not merely as the absence of disease. The “planetary health plate”, based on this scientific evidence, should consist by volume of approximately half a plate of vegetables and fruits; the other half, displayed by contribution to calories, should consist of primarily whole grains, plant protein sources, unsaturated plant oils, and (optionally) modest amounts of animal sources of protein (Fig 19).

[32] Willett W., 2019. Food Planet Health - Healthy Diets from Sustainable Food Systems. EAT-Lancet Commission Summary Report
[33] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House
[34] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House
[35] W. Willett et al., Food in the Anthropocene: the EAT Lancet Commission on healthy diets from sustainable food systems. Lancet 2019; 393: 447–92.

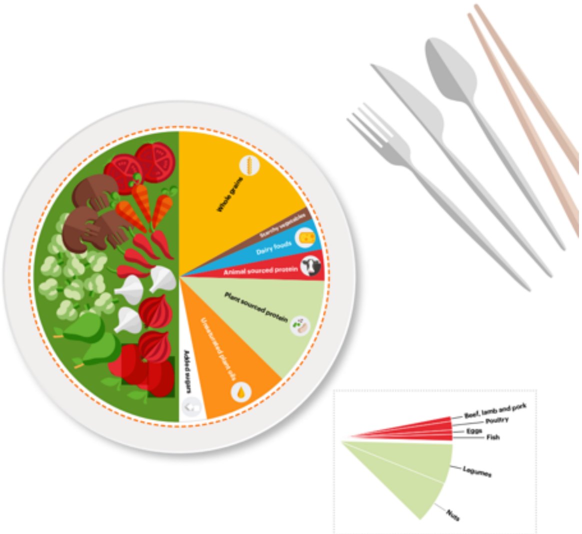

Fig 19: Planetary Health Diet proposed by the EAT-Lancet Commission[36]

The Planetary Health Diet does not suggest that we should all be eating the same diet, rather it gives us the scientific knowledge about what is good and healthy for us and leaves plenty of space for each culture to interpret how to accommodate specific food traditions. Eating according to the guidelines for the Planetary Health Diet not only increases your health but also contributes to safeguard the stability of the planet.

Transformation to the Planetary Health Diet by 2050 will require substantial dietary shifts. This includes a more than doubling in the consumption of healthy foods such as fruits, vegetables, legumes and nuts, and a greater than 50% reduction in global consumption of less healthy foods such as added sugars and red meat (i.e., primarily by reducing excessive consumption in wealthier countries). However, some populations worldwide depend on agropastoral livelihoods and animal protein from livestock, which is why the role of animal source foods in people's diets must be carefully considered within local and regional realities.

The health benefits of adopting the Planetary Health Diet are substantial as it is estimated to prevent approximately 11 million premature deaths per year, accounting for between 19% to 24% of total deaths among adults. It will also assure we produce sufficient high-quality food to feed the growing population, including the 820 million people that still lack sufficient food, and many more that consume either low-quality diets or too much food.

TARGET 2 – Sustainable Food Production

We need a global transition towards farming practices that capture rather than release carbon, that circulate nutrients rather than pollute, and that save water rather than waste it. We need sustainable agriculture, a trend that is already been picked up by 28% of farmers worldwide[37].

Interacting earth systems and processes regulate the state of the planet. The EAT-Lancet Commission has identified the six main systems and processes that are directly affected by food production and for which scientific evidence allows the provision of quantifiable targets. For each of these, the Commission proposes boundaries that global food production should stay within to decrease the risk of irreversible and potentially catastrophic shifts in the Earth system (Fig 20).

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[36] Willett W., 2019. Food Planet Health - Healthy Diets from Sustainable Food Systems. EAT-Lancet Commission Summary Report
[37] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House

	Control variable	Boundary (uncertainty range)
Climate change	Greenhouse-gas (CH_4 and N_2O) emissions	5 Gt of carbon dioxide equivalent per year (4·7–5·4)
Nitrogen cycling	Nitrogen application	90 Tg of nitrogen per year (65–90;* 90–130†)
Phosphorus cycling	Phosphorus application	8 Tg of phosphorus per year (6–12;* 8–16†)
Freshwater use	Consumptive water use	2500 km³ per year (1000–4000)
Biodiversity loss	Extinction rate	Ten extinctions per million species-years (1–80)
Land-system change	Cropland use	13 million km² (11–15)

*Lower boundary range if improved production practices and redistribution are not adopted. †Upper boundary range if improved production practices and redistribution are adopted and 50% of applied phosphorus is recycled.

Fig 20: Scientific targets for six key Earth system processes and the control variables used to quantify the boundaries[38]

The transition to sustainable agriculture needs a guiding principle as was identified in the "Carbon Law" for the energy transition. Rockström and Gaffney propose that such guiding principle should be the "zero target for nature principle", which suggests that since we have already transformed 50% of Earth's land-based ecosystems to agriculture, cities, roads etc., in order to feed the growing population we should only be using the land that we have already converted and make sure that our current cropland stores more carbon rather than it releases. There are already a series of practices paving the way for this new 'green revolution,' primarily based on regeneration and recirculation. This movement must incorporate integrated solutions that combine aspects such as water productivity, soil health, nutrient recycling, crop rotations, and watershed design, along with advancements in biotechnology.[39]

The zero target for nature encompasses several crucial actions. Firstly, it involves an urgent halt to the destruction of the world's remaining forests. This action alone accounts for roughly half of the emissions reductions required from this sector by 2030. Additionally, the target involves promoting reforestation, which stands as the most significant approach to absorbing carbon from the atmosphere. Moreover, the strategy includes the restoration of degraded peatlands, which serve as vital natural carbon sinks. Lastly, it incorporates improved wildfire management, a critical measure considering wildfires currently contribute to 5 to 10% of the annual global CO2 emissions.

Five strategies forward

The analysis shows that staying within the safe operating space for food systems requires a combination of substantial shifts toward mostly plant-based dietary patterns, dramatic reductions in food losses and waste, and major improvements in food production practices. While some individual actions are enough to stay within specific boundaries, no single intervention is enough to stay below all boundaries simultaneously.

According to the EAT-Lancet Commission, the data are both sufficient and strong enough to command immediate action. Delaying action will only increase the likelihood of serious, even disastrous, consequences. It is clear too that a Great Food Transformation will not occur without

[38] Willett W, Rockström J, 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems, The Lancet

[39] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House

widespread multi-sector, multi-level action, which must be guided by scientific targets[40]. The following five strategies are essential to get the food transformation going:

STRATEGY 1: Seek international and national commitment to shift toward healthy diets

Around half of the countries around the world have drawn up national dietary guidelines, most of which are based solely on the health effects of food and only a handful of which take both health and the environment into account, including: Brazil, the Netherlands, Qatar, Canada and Sweden[41].

The scientific targets set out by the EAT-Lancet Commission provide guidance for the shift needed to take both health and the environment into account. It recommends increased consumption of plant-based foods, including fruits, vegetables, nuts, seeds and whole grains, and substantially limiting animal source foods. This concerted commitment can be achieved by including environmental considerations into national dietary guidelines, by making healthy foods more available, accessible and affordable in place of unhealthier alternatives, by improving information and food marketing, by investing in public health information and sustainability education, and by using health care services to deliver dietary advice and interventions.

It is important to note that unlike the relationship between diet and health, where we can use a single indicator (increased life expectancy) as the yardstick, the relationship between diet and environment is more complex as we cannot use a single yardstick but must use various yardsticks and necessarily apply priority criteria i.e., what is more important: increased life-expectancy or reduced CO2 emissions? While this goes beyond the scope of this paper, it is sufficient to say that scientists have highlighted that there are clear synergies between healthy and sustainable diets. Plant-based food like fruits, vegetables, nuts and seeds, which are good for our health, are also generally less resource-intensive. Similarly, animal-based products such as red and processed meats tend to be worse for our health and that of our planet[42]. There are of course exceptions such as sugar beets and cane which are not as such bad for the environment but not good for our health, or the consumption of fish, which is in principle good for our health, but problematic for the environment due to the risk of over-exploitation and depletion.

STRATEGY 2: Reorient agricultural priorities from producing high quantities of food to producing healthy food

Over the years, the detrimental effects of unsustainable food production on natural resources and ecosystems have weakened the resilience of farming systems, evident in serious soil depletion. When resilience is reduced, farming systems become more vulnerable to threats such as pest outbreaks and extreme weather events. Monoculture farming is one example where high short-term yields and profitability is prioritised at the expense of soil depletion and reduced biodiversity.

Agriculture and fisheries must not only produce enough calories to feed a growing global population but must also produce a diversity of foods that nurture human health and support environmental sustainability. Alongside dietary shifts, agricultural and marine policies must be reoriented toward a variety of nutritious foods that enhance biodiversity rather than aiming for increased volume of a few crops exclusively.

[40] Willett W, Rockström J, 2019. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems, The Lancet
[41] Rockström, J. Bignet, V., Landqvist M., Stordalen G., 2018. The World-Changing Cookbook, Max Stroem
[42] Rockström, J. Bignet, V., Landqvist M., Stordalen G., 2018. The World-Changing Cookbook, Max Stroem

Agro-ecology practices are gaining popularity due to their integration of food production with the natural ecology of the land, ensuring the maintenance of the land's ecosystem services and cycles. Examples include reusing manure as fertiliser or to produce biofuels, crop rotation using different and complimentary plants to increase biodiversity and increasing the use of cutting-edge technologies in production such as vertical farming where farmland is in short supply.

STRATEGY 3: Sustainably intensify food production to increase high-quality outputs

Even people who follow a healthy diet may be exposed to health risks because of unsustainable food production practices (use of fertilisers, antibiotics, pesticides) that both affect the environment and our health.

The existing global food system calls for a novel agricultural revolution that can seamlessly integrate increased productivity with the tenets of sustainability and systemic innovation. The latter would entail achieving a minimum of 75% reduction in yield gaps on current cropland, making substantial advancements in the efficiency of fertilizer and water usage, reusing phosphorus, rethinking the worldwide distribution of nitrogen and phosphorus utilization, adopting climate mitigation strategies such as altering crop and feed management, and fostering increased biodiversity within agricultural systems. In addition, to achieve negative emissions globally as per the Paris Agreement, the global food system must become a net carbon sink from 2040 onwards.

STRATEGY 4: Strong and coordinated governance of land and oceans

While in the past the global commons have been limited to the four zones beyond national jurisdiction: Antarctica, the High Seas, outer space and the atmosphere, Rockström and Gaffney argue that in the Anthropocene, the global commons should include all parts of the Earth system that protect Earth's stability – i.e., all areas within the planetary boundaries[43] so that the global community can collectively do what needs to be done to protect the people and planet and meet the objectives outlined by the 2030 Agenda and the Paris Agreements.

Protecting the people and the planet implies designing and implementing global targets and solutions that strive to keep us within all of the planetary boundaries, among which we recall zero-expansion of new agricultural land into natural ecosystems and species-rich forests, restoration and reforestation of degraded land, enhancement of biodiversity and ocean conservation.

STRATEGY 5: At least halve food losses and waste

While large differences exist between countries, on average approximately 30 % of all food produced in the world is lost or thrown away. In developing countries this is mostly due to transport and storage problems as food spoils quickly without proper refrigeration. In developed countries, this phenomenon is largely linked to consumer choices. Here, we tend to spend comparatively less on food, leading to a sense of disposable abundance. Oversized portions are commonplace, often exceeding our capacity to consume them, and effectively managing leftovers remains a challenge. Furthermore, "ugly" fruit and vegetables are discarded as they do not meet certain characteristics or displease the consumer. Many of these issues can be solved with increased consumer awareness and common-sense initiatives.

Bearing in mind that the population is expected to increase to 11 billion people, and that there are still over 800 million people that go hungry every day, it is absolutely madness that 30% goes to waste. If we do not tackle food waste and cut down on the most resource-intensive foods, we will

[43] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House

need to produce 50 - 70% more food by 2050[44]. Food waste is therefore not only a completely unnecessary environmental burden but also a matter of food security and equity.

Substantially reducing food losses at the production side and food waste at the consumption side is essential for the global food system to stay within a safe operating space. Both technological solutions applied along the food supply chain and implementation of public policies are required in order to achieve an overall 50% reduction in global food loss and waste as per the targets by the SDGs. Actions include improving post-harvest infrastructure, food transport, processing and packing, increasing collaboration along the supply chain, training and equipping producers, and last but not least educating consumers.

As we have seen, introducing sustainable food systems will be a defining issue of the 21st century. Unlocking its potential will catalyse the achievement of both the SDGs and the goals set by the Paris Agreement. An unprecedented opportunity exists to develop food systems as a common thread between many international, national, and business policy frameworks aiming for improved human health and environmental sustainability for all people and the planet.

4.3 CASE STUDY: The European Green Deal

In order to understand what steps need to be taken to reach net-zero in practice, it is useful to look at a large regional example. The European Union's recently adopted "EU Green Deal" provides a good example of how to plan for net-zero GHG emissions by 2050.

The overarching objective of the EU Green Deal is for the EU to become the first climate neutral continent by 2050, resulting in a cleaner environment, more affordable energy, smarter transport, new jobs and an overall better quality of life for all. To deliver on this objective the EU Green Deal proposes specific strategies that can help curb emissions across all sectors, with a strong focus on reducing GHG emissions from all contributing sectors.

Second, the EU Green Deal strives to decouple growth from resource exploitation. While reductions in emissions have been achieved in the last decade, Europe remains one of the major contributors of resource consumption in the world. Described as a "generation-defining task," achieving this objective will not only require a boost in technological advancements but also rethinking lifestyles, communities, and societies.

Third and finally, the EU Green Deal acknowledges the need to foster an inclusive green transition and to leave no one behind. This commitment is reinforced through the Just Transition Mechanism, which aims to alleviate the socio-economic impacts, especially for the most vulnerable, of the transition needed.

The EU Green Deal outlines the long-term net-zero objectives for the European Union. Achieving these goals necessitates a comprehensive and interconnected policy response. This process involves revising existing legislation to align with the EU Green Deal objectives and drafting new legislation to address any identified gaps. Such policies will in many cases be interlinked and must be mutually reinforcing and striving for the same long-term objectives. This will be an ongoing process, evolving alongside technology, standards, and available financing. Therefore, adjustments and amendments will be required until the ultimate goals are achieved.

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[44] Rockström, J. Bignet, V., Landqvist M., Stordalen G., 2018. The World-Changing Cookbook, Max Stroem

The GHG emissions from the energy sector of the European Union will be 93% lower than 1990 levels in 2050, with remaining emissions eliminated using Direct Air Capture (DAC). In the power sector, virtually all unabated coal generation is phased out by 2030 and natural gas substantially reduced by 2050. Renewables account for 75% of new power generation capacity additions to 2050, with offshore wind and solar PV leading the way. By 2050, offshore wind is the single largest source of electricity, providing over a quarter of electricity supply, followed by onshore wind, nuclear power, and solar PV.

Food systems are responsible for around 21-37 % of global greenhouse gas emissions[45] in the EU and use up significant natural resources. The "Farm to Fork Strategy" aims to address these environmental issues as well as fairness, sustainability of the food system and the health of Europeans. The strategy will focus on reducing waste, and transforming the manufacturing, processing, retailing, packaging and transportation of food[46].

On average we have observed a 60% decline in the size of populations of mammals, birds, fish, reptiles, and amphibians in just over 40 years[47]. The "EU Biodiversity strategy for 2030" identifies the key drivers in biodiversity loss as changes in land and sea use, overexploitation, climate change, pollution, and invasive alien species. It furthermore highlights how biodiversity loss and climate change are intrinsically linked, and that nature-based solutions will play an important role in mitigating, and adapting to, climate change.

Concluding remarks

The message is clear: to stand a chance of deviating away from the climate disaster, and to maintain the ecological capacity on earth to feed humanity, we need to follow both the carbon law for energy and the zero law for nature[48].

As we have observed in the IEA NZE roadmap, if we are to reach net-zero objectives by 2050 then renewable technologies like wind and solar PV coupled with a massive push for electrification and increased storage capacity could put us on the right path to halve emissions by 2030. The period from 2030 to 2050 will need to scale-up technologies and modern fuels that are still in the development stage such as CCUS, green hydrogen and bioenergy, for which significant efforts are currently being made.

When it comes to food systems, it is clear that the 10.000 yearlong era of agricultural expansion must come to an end. We have already transformed half of Earth's surface; we must therefore keep the other half intact at all costs. To achieve this goal, it is imperative that we transform every hectare of land from carbon source to carbon sink. Furthermore, these lands should support a wider array of crops, as well as provide a habitat for diverse wildlife and insects. Additionally, each hectare of land should possess inherent resilience to effectively cope with inevitable shocks like droughts, floods, cold spells, and heatwaves.

If we are to create the right conditions for a net-zero world, then we must assure that governments and industries are fully on-board and together strive for the net-zero future we all want. Research indicates that financial and regulatory measures are the most effective in achieving results, and why it is important for governments to push for positive change via a combination of hard measures,

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[45] IPCC Special Report on Climate Change, Desertification, Land Degredation, Sustainable Land Management, Food Security, Greenhouse Gas Fluxes in Terrestrial Ecosystems, eds P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts.
[46] European Commission, Farm to Fork Strategy, https://ec.europa.eu/food/system/files/2020-05/f2f_action-plan_2020_strategy-info_en.pdf
[47] WWW, Living Planet report 2018
[48] Rockström, J., Gaffney, 2021. Breaking Boundaries – The Science of our Planet, Penguin Random House

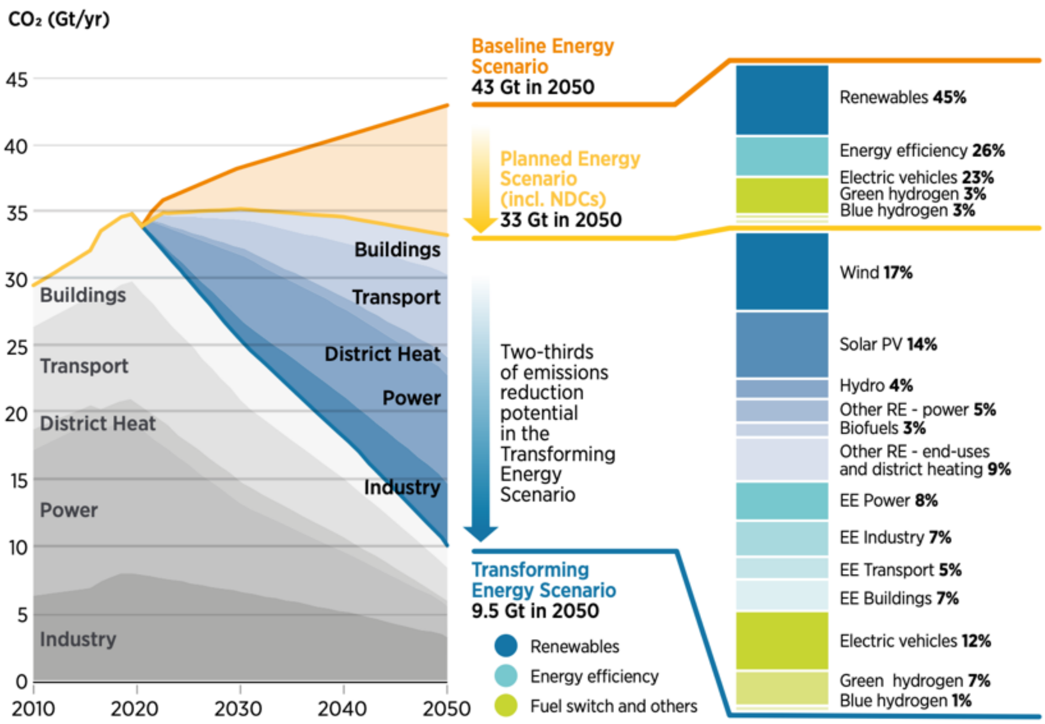
such as taxation, incentivisation and certification, and soft measures, such as public awareness campaigns and labelling schemes.

While taste, comfort and price are fundamental to consumer choices, researchers have documented that health and environmental benefits also have significant impact on consumers preferences. Key to many of the transformations needed are behavioural changes of the consumers. To achieve the scale of the energy and food sector transformation needed the consumer has a strategic position as the driver of demand. Overall societal norms and personal choices will therefore play a central role in reaching the long-term goals of net-zero.

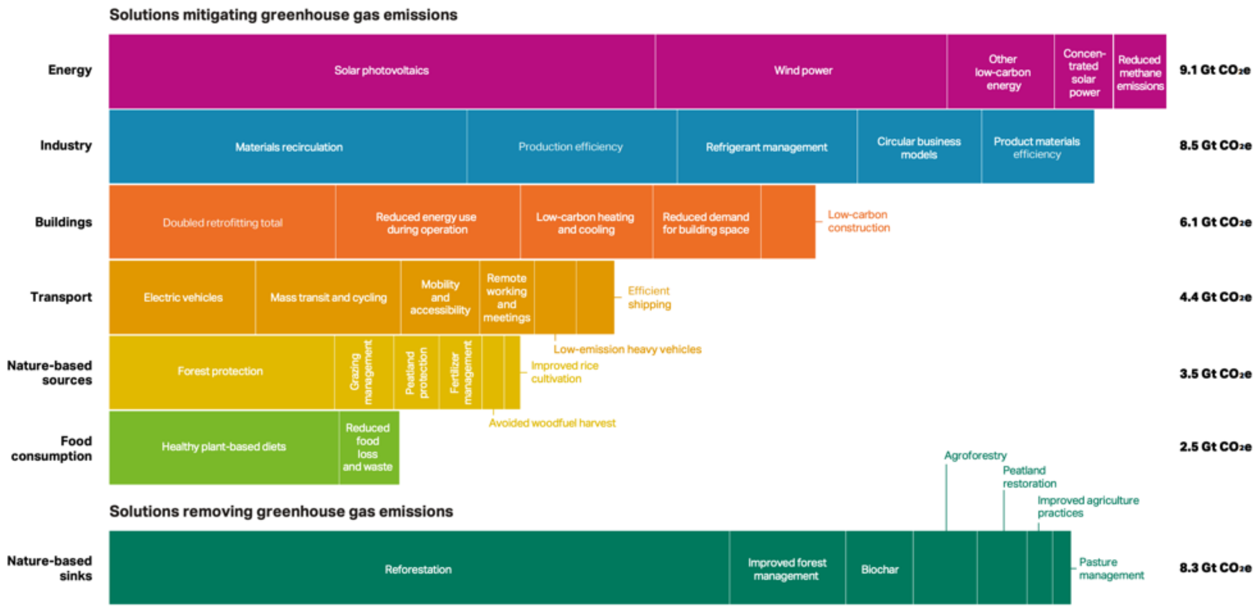
Finally, global cooperation is key to the planetary stewardship needed to react a net-zero world. Cooperation stands as one of the most potent forces within democratic societies. Throughout history, remarkable accomplishments have arisen from the synergy of cooperation. Examples include addressing the ozone layer depletion, combatting acid rain, globally prohibiting atmospheric nuclear testing, and developing a COVID-19 vaccine in record time. Now, we must collectively re-evaluate our connection with Earth and take the necessary actions to restore its stability.

Annex

Annex 1 – IRENA Roadmap to Net-Zero[49]



Annex 2 - Gaffney's Exponential reductions Roadmap by 2030[50]



[49] Figure from IRENA, Global Renewables Outlook: Energy Transformation 2050
[50] Figure from: Falk J., Gaffney O., 2020. Exponential Roadmap - Scaling 36 solutions to halve emissions by 2030 p.18

Annex 3 - EAT-Lancet commission Scientific targets for a planetary health diet, with possible ranges, for an intake of 2500 kcal/day.[51]

	Macronutrient intake grams per day (possible range)	Caloric intake kcal per day
Whole grains		
Rice, wheat, corn and other	232	811
Tubers or starchy vegetables		
Potatoes and cassava	50 (0–100)	39
Vegetables		
All vegetables	300 (200–600)	78
Fruits		
All fruits	200 (100–300)	126
Dairy foods		
Whole milk or equivalents	250 (0–500)	153
Protein sources		
Beef, lamb and pork	14 (0–28)	30
Chicken and other poultry	29 (0–58)	62
Eggs	13 (0–25)	19
Fish	28 (0–100)	40
Legumes	75 (0–100)	284
Nuts	50 (0–75)	291
Added fats		
Unsaturated oils	40 (20–80)	354
Saturated oils	11.8 (0-11.8)	96
Added sugars		
All sugars	31 (0–31)	120

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