Chapter 13
Discussion, Conclusions and Recommendations

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> *The Paris Agreement central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 °C.*
>
> UNFCCC (2015)

Abstract The following section focuses on the main findings in all parts of the research, with priority given to high-level lessons, to avoid the repetition of previous chapters. The key findings as well as the research limitations and further research requirements are given for following topics:

Renewable energy potential mapping, Transport scenario and long-term energy scenario development, power sector analysis, employment and mineral resource implications for the 2.0C and 1.5C scenarios and non-energy GHG scenarios,

Policy recommendations for the energy sector with a focus on policies for buildings sector decarbonisation, for the transport and industry sector as well as a recommended political framework for power markets are provided.

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The Paris Agreement's goals require significant change in how we use and produce energy on a global level. This energy transition must be started immediately and without further delay, and concerns energy-producing industry and utilities as well as every energy consumer—from the industry level down to the residential sector. A combination of energy efficiency and the use of renewable energies will involve new business concepts for the energy sector, which will require entirely new policies that provide a new market framework. The implementation of new technologies and business concepts will include policy changes on the community level as well as by national governments and international organizations. While the 2.0 °C Scenario allows for a 3–5 years transition period in which to implement policy measures, the 1.5 °C Scenario allows no further delay but requires an immediate start, at the latest in 2020. Therefore, the 1.5 °C Scenario presented in this book provides a technical pathway that assumes and allows no political delay, and may therefore be seen as a technical benchmark scenario.

However, this energy transition cannot be seen in isolation. To stay within the Paris Agreement Goal requires reductions in greenhouse gas (GHG) emission that are greater than can be delivered by the energy transition alone (see Chap. 4). However, there are technical and logistical limits to how fast new technologies can be implemented. The establishment of efficient transport systems and industry processes, or simply the provision of required renewable energy and storage technologies will require a minimum time. Production capacities must increase significantly, people must be trained, and existing buildings must be retro-fitted. Infrastructural changes, such as smart power grids, must be planed, construction permits must be issued. The energy transition will require political determination and public acceptance. Therefore, the planning process will require resolute stakeholder involvement. Furthermore, a fundamental shift in today's resource-intensive lifestyles seems unavoidable if we are to limit global warming. In particular, the way consumption and mobility are organized in developed countries today will challenge planetary boundaries to the extreme if they remain at their current levels.

During the development of the energy scenario pathways, it became clear that even the most ambitious 'man-on-the-moon' program—if focussed only on the energy sector—would not be enough. Therefore, the political framework required to implement the Paris Agreement on national levels must also take the land-use sector, as well as the main GHGs, methane, N_2O, and fluorinated gases, into account.

The following sections present the main findings and lessons of this research project, and highlight its limitations and further research requirements. Finally, we provide policy recommendations for the energy sector in order to implement the -energy scenarios.

13.1 Findings and Limitations—Modelling

The following section focuses on the main findings in all parts of the research, with priority given to high-level lessons, to avoid the repetition of previous chapters.

13.1.1 Key Findings—Renewable Energy Potential Mapping

Various research projects have analysed renewable energy potentials and all have in common that the renewable energy potential exceeded the current and projected energy demands over the next decades by an order of magnitude. However, regional distributions are uneven, and especially in densely populated regions, such as urban areas, the local renewable energy resource might be unable to supply the demand. Therefore, renewable energies might have to be transported by power lines or in the form of gasified or liquid renewable fuels to the demand centre. However, all 10 regions and 75 sub-regions examined had sufficient renewable energy resources to meet the regional needs.

13.1.2 Limitations and Further Research—Renewable Energy Potential

The quality of data varies significantly across the regions and especially detailed high-resolution surveys have their limits. Due to the limited available data, detailed mapping of the Eurasia region—especially for Russia and parts of central Asian countries—was not possible. Therefore, in this case, we relied on research published in the scientific literature. Onshore wind data were generally only available for 80 m above the ground, whereas no data for 100–120 m were available in most cases. However, modern wind turbines operate at those higher levels and wind resources are generally better at these elevations. Therefore, further research is required using open source data for onshore and offshore wind data at the 100 m level.

13.1.3 Key Findings—Transport Scenario

Transport modelling has shown that the 2.0 °C and 1.5 °C pathways can be met when strong and determined measures are taken, starting immediately. They include rapid electrification across passenger and freight transport modes, a shift towards more energy-efficient transport modes, and a build-up of biomass and synfuel capacities for the transport modes that are less inclined towards electrification due to range or constructional constraints, as is the case in aviation. In the road subsector, which is the most relevant emission source in the transport area, battery electric and fuel-cell electric vehicles must be widely introduced, which will also require a stringent parallel build-up of recharging and refuelling infrastructures.

In general, we found that beyond pure technical measures with regard to powertrain shifts and overall efficiency enhancements, fundamental changes in today’s mobility patterns will also be required to meet the 2.0 °C Scenario, and even more so for the 1.5 °C pathway. This will apply particularly to the car use habits in the OECD countries. In essence, definite limitations on transport activities and modal shifts towards mainly buses and railways in some world regions and sub-sectors will be required to meet the Paris goals. However, the Non-OECD world regions will mainly increase their overall transport activity until 2050. The 2.0 °C and 1.5 °C transport scenario pathways will not be achieved automatically, but will require long-sighted infrastructural and transport policy framework settings on both inter- and intra-governmental levels.

13.1.4 Limitations and Further Research Requirement—Transport

The statistical databases for several world regions on transport activities and fleet and powertrain shares are limited, and in those cases, projections, conclusions by analogy, and estimations were required in our modelling. Therefore, further studies should focus on enhancing these databases and specify the modelling in more detail, which could also include case studies of countries instead of regions, to better address spatial particularities in the transport models. Detailed investigations of mode shift potentials, based on infrastructure capacity constraints, were considered to some extent, but deserve more in-depth modelling in future works. Further research is required to refine the coupling of renewable energy potentials, transport infrastructure upgrades, and the expansion of on-board energy storage usage.

13.1.5 Key Findings—Long-Term Energy Scenario

The 2.0 °C and the 1.5 °C scenarios both represent ambitious pathways that require fundamental changes in current energy consumption and supply. The key strategies of these pathways are the implementation of renewable energy technologies and efficiency improvements in all sectors. The electrification of the transport and heating sectors and the diversification of supply technologies are core elements of both alternative scenarios. Besides numerous technical and structural improvements, behavioural changes among end-users and major changes in investment activities and strategies must be achieved. This applies, for example, to the per capita electricity consumption (electric appliances without heating) of 'residential and other sectors', which will decrease in OECD countries by one third between 2015 and 2050 in the 1.5 °C Scenario, but will grows in the non-OECD regions by only 70% in the same period. This could imply limitations on personal consumption compared with today's standards, particularly in OECD countries—at least for as long as fossil fuels still play a significant role. Another example is the final energy demand per $GDP in the 'Industry' sector, which will decrease by 65% in OECD regions and by 80% in non-OECD regions, an ambitious pathway that will require stringent technology change and replacement strategies and supporting regulatory and governance measures to trigger huge investments for its realization.

On the energy supply side, considerable contributions in the future are assumed from wind and solar power, electrification and synthetic fuel use in transport and heating, sustainable biomass use, especially for co-generation and biofuels, and district heating systems that integrate solar, geothermal, and ambient heat potentials. The exploitation of renewable energy potentials depends strongly on regional conditions. In regions such as India and China, a 100% renewable electricity supply will require the extensive use of existing potentials. The global installed capacities of renewable power generation technologies will increase by a factor of more than 12, from 2000 GW in 2015 to more than 25,000 GW in 2050. Cumulative investments for power generation are estimated to increase between 2015 and 2050 by up to around US$ 50,000 billion compared with around US$20000 billion in the reference case. Fuel cost savings could offset around 90% of the additional investment costs as consequence of the fossil fuel phase-out and reductions in demand, but without considering the additional infrastructure demands of the transition arising from grid expansion, storage, and other flexibility demands. In the scenarios, large-scale and long-range electricity transport between Europe and the MENA countries is assumed to be a possible and promising example of supra-regional exchange between regions of production and regions of demand. Many of these import/export relationships must also be realized among countries *within* individual world regions (which are thus not resolved in our model) to increase the security and cost-efficiency of the energy supply. Decentralization and digitalization, but also the efficient implementation of new respectively the expansion of existing central infrastructures, are other implicit core elements of the scenario narratives. The large-scale generation and use of synthetic fuels are expected to play key roles in the deep-decarbonisation scenario, at least if the intensity of today's freight transport and air traffic is to be maintained, despite the huge energy losses this option will have. Both alternative scenarios, especially the 1.5 °C Scenario, require a rapid reduction in the final energy demand and, as far as possible, stagnation in the strong global growth in the demand for energy services, at least for as long as fossil energies dominate the energy supply structures.

Besides the structural similarities between both the 2.0 °C and 1.5 °C Scenarios, one main difference between them is the rate of transformation: To maintain the average global temperature increase due to climate change below 1.5 °C, the transformation must be accomplished as fast as technically possible. The trend in increasing global energy-related CO_2 emissions must be reversed as soon as possible (in the early 2020s, at the latest) and emissions must be reduced by 70% in 2035 and by 85% in 2040 (compared with emission levels in 1990). Every single year without significant emission reductions on the global level will dramatically reduce our chance to confine global warming to 1.5 °C. In contrast, in the 2.0 °C Scenario, emission reductions in 2035 may be in the order of 40% and 65% in 2040, leaving a little more time for the transition process.

13.1.6 Limitations and Further Research Requirement—Long-Term Energy Scenario

The 1.5 °C Scenario may seem more difficult than similarly ambitious scenarios that were made 10 to even 20 years ago. However, the opportunities to respond to climate change have been largely wasted in the last two decades, and all transition processes have faced huge obstacles in the past due to the inertia and conflicting aims of societies, governments, and most relevant stakeholders. Too often, more attention has been paid to doubters than to facts. Therefore, the scenarios also show that the longer the governments wait, the more difficult it will be to prevent severe climate damage and the greater will be the technical and economic challenges that will be encountered in the energy system transformation.

The coarse regional resolution of such global scenarios does not allow sufficient account to be taken of sub-regional differences in energy demand and the characteristic and favourable possibilities of sustainable supply. However, it can provide rather fundamental insight into basic technical and structural possibilities and requirements of a target-oriented pathway. Our results clearly reveal and quantitatively describe that the coming years will be most critical regarding a successful energy transition because for both parts of the energy transition—efficiency improvement/demand reduction and the implementation of new technologies—huge investments and fundamental changes in producing, distributing, and consuming energy will be needed. Such transformation processes must be analysed and planned carefully under the complex economic and societal framework conditions of each region, down to the country, sub-country, and community levels. Such analyses can then form the basis for the further investigation of the economic implications of these pathways.

Another limitation of this approach is that the economic, technical, and market assumptions made probably have limited consistency. Carbon, fuel, and technology costs are assumed independently of the assumptions regarding overall economic development and the final energy demand. It also remains unclear to what extent the energy transition will change the overall material demand and activity of the manufacturing industry. Furthermore, which economic framework conditions and market mechanisms will be necessary for rapid decarbonisation remain largely unclear, as is whether the current market mechanisms are capable of supporting the fundamental paradigm shift of this target-oriented energy transition.

13.1.7 Key Findings—Power Sector Analysis

Although there are significant differences across all the regions and sub-regions analysed, there are some similarities:

Increasing loads: The loads in all regions will increase significantly between 2020 and 2050, due to increased electrification of the transport and, to some extent, the heating sectors. Higher loads will require the adaptation of power-lines and transformer stations, especially on distribution grids where electric vehicles are most likely to be charged.

Increasing reverse power flows: Almost all regions will have periods of negative residual load, when generation is higher than the required load within a specific period of time. This leads to reversed power flow, and the generated electricity must be transported to other regions. The dominant power-generation technologies are wind and solar photovoltaic (PV). Solar PV is mainly connected to the distribution grid and export requires that the electricity must be able to flow from low- to medium-voltage levels, which requires adaptation at transformer stations.

Ratio between maximum variable generation capacity and maximum load: The results presented in Chap. 8 suggest that a ratio of 180% variable renewable capacity to the maximum load represents the optimum relationship. If the capacity were higher, short-term peaks would appear more frequently, which would lead to higher curtailment, or high storage and transmission demands. Example: The maximum load of a region is 100 GW and the installed capacity of wind and solar PV combined is 180 GW. Short-term peaks are relatively rare, and curtailment is below 10% of the total annual generation potential. If the variable power generation were above 200 GW, while the load remained at 100 GW, the curtailment rates would increase significantly, to 15% and higher.

Technology variety reduces storage demand: The combination of solar PV and wind leads to a lower storage demand than does a solar- or wind-dominated supply scenario. The relative interaction between the available wind and solar resources, not just in regard to day and night, but also seasonally, will reduce the storage demand in all regions. Therefore, the levelized cost of electricity generation cannot be seen in isolation. Even if, for example, wind is more expensive than solar PV in one region, a combination of wind and solar will lead to a reduction in storage demand and lower systems costs.

Variety in storage technology and sector coupling: The combination of battery and hydro pump storage technology and the conversion of the gas sector to hydrogen and synthetic fuels will be beneficial. The hydrogen produced can be used for the management of demand, and hydrogen-fuelled power plants can provide valuable dispatch services.

13.1.8 Limitations and Further Research Requirement—Power Sector Analysis

Measured load curves for regions, countries, or states/provinces are often unavailable and, in some countries, are even classified information. Therefore, it was not always possible to compare the calculated loads with actual current actual. However, the comparison of 2020 calculations with current maximum loads for regions and countries with published data showed that the calculations were within a ± 10% range. However, verification was not possible for several regions. Therefore, our analysis may over- or underestimate the current loads and therefore the future projections of loads as well. Therefore, the optimal ratio of maximum load to installed variable capacity requires further research.

More research is also required to verify the thesis of an optimal ratio between the variable generation and maximum load, because the sample size of this study was not sufficient to ensure validity. Furthermore, the optimal mix of solar and wind requires better meteorological data and actual measured load profiles. Access to more detailed data to calculate more case studies is vital to determining the possible optimal combination of wind and solar.

13.1.9 Key Findings—Non-energy Scenarios

The key finding of the land-use-related emission scenarios is that a dedicated concerted effort to sequester carbon by reforestation and forest restoration could re-establish the terrestrial carbon stock of pre-industrial times. That would undoubtedly come with multiple co-benefits, but would not be without challenges. After all, there is a reason why humans in the various corners of the planet pursued deforestation, whether for short-term and short-sighted gains or to establish agricultural areas that fed an increasing population. Therefore, land-use conflicts and trade offs are an inherent part of future mitigation actions, whether CO_2 sequestration is pursued by reforestation sequestration or by some biomass and CCS use. Nevertheless, the important result of this study is that the addition of land-use CO_2 and other GHG emission pathways to energy-related scenarios yields scenarios that stay below or get below 1.5 °C warming without a reliance on massive net negative CO_2 emission potentials towards the second half of this century.

Going beyond the land-use CO_2 emission pathways that we sketched for a series of sequestration options, we also designed trajectories for all the other GHGs and aerosols. An unprecedented wealth of scenario information is now available thanks to the recent concerted efforts of the larger integrated assessment community. Designing a novel method here, the Generalized Quantile Walk method, we were able to distil non-CO_2 pathways from this rich scenario database—in a way that respects the correlations and dependencies between energy-related CO_2 and other gas emissions. This is not only a new methodological advance in scenario research, but also key to the proper estimation of the climate effects of the energy-related CO_2 scenarios designed in the main part of this study.

13.1.10 Limitations and Further Research Requirement—Non-energy Scenarios

There are a number of limitations associated with the derived non-energy-related emission trajectories. Possibly the most important opportunity for future research will involve a more fine-grained look at land-use-based sequestration options in various countries and biomes. This study assumed only a rather coarse approximation of the available land areas, sequestration rates, and cumulative changes in land carbon stocks to estimate the potential and time trajectories of those reforestation, forest restoration, agroforestry, and other land-based sequestration options.

In terms of the non-CO_2 emission trajectories, this study relied heavily on the collective wisdom embodied within a large set of literature-reported scenarios. Although we have designed probably the most advanced method to distil that knowledge into emission trajectories that are consistent with our energy-related pathways, this meta-analytical approach is not without its limitations. In particular, a bottom-up energy-system and land-use/agricultural model must be able to estimate methane and N_2O emissions from various agricultural activities in a more coherent way, which could provide results on a regional level. Such regionally and sectorally specific information would, in turn, allow the examination of various mitigation options for non-CO_2 emissions. This bottom-up modelling capacity is missing from our meta-analytical approach.

13.1.11 Key Findings—Employment Analysis

The occupational employment analysis was developed in 2018 to improve the database for the ‘just transition’ concept. Not only is the number of jobs that will be created or lost as a result of a global or regional energy transition important, but also the specific occupations that will be to develop a socially sound transition. This analysis breaks new grounds because very little information has been available. However, the results indicate that even within the seven occupation types, job losses are the exception and almost all trades will gain more jobs.

Very specialized jobs, such as machine operators in coal mines, will be lost and there will be no replacement. Therefore, a detailed analysis of all sectors is required to identify those highly specialized tasks and to develop re-training possibilities.

13.1.12 Limitations and Further Research Requirement—Employment Analysis

The data available on the detailed employment requirements for renewable energies are very limited. Although there are some data for solar PV and onshore and offshore wind, there are almost none for concentrated solar power plants or geothermal energy. Furthermore, occupational surveys of the heating and energy efficiency sectors are required.

13.1.13 Key Findings—Mineral Resource Analysis

Lithium sees the highest projected increase from mined ore of around 40 times current production to above 80 times current production should future technologies be introduced without recycling.

Cumulative primary lithium demand by 2050 for the majority of scenarios is above current reserves of lithium except for the "potential recycling" scenario but less than known resources. The scenarios anticipate a scale up in resource exploration, discovery and production for primary resources to meet demand—assuming lithium-ion batteries continue to dominate as the chemistry of choice. It is important that future mines be responsibly developed and that battery designs be compatible with circular-economy thinking. Significant infrastructure for reuse and recycling will need to be developed to achieve high rates of lithium recycling.

For cobalt, future scenarios exceed currently known reserves and approach currently known resources in 2050. Given the concentrated supply source from the Democratic Republic of Congo, this will continue to keep pressure on exploring alternative battery chemistries and on increasing cobalt recycling. Attention must continue to be paid to reducing the social and environmental impacts of supply whilst supporting development noting the significant adverse impacts on human and environmental health associated with cobalt mining. While the value of cobalt in EV battery recycling is already an important component of the recycling economics because of supply limitations, the social and environmental challenges provide a further driver for increasing recycling.

For silver, the potential of materials efficiency (using less silver per GW solar PV panel) has potential to reduce demand owing to the long lifetimes of PV panels. Under some scenarios using future technology with recycling, the levels of silver demand are similar to current production.

13.1.14 Limitations and Further Research Requirement—Mineral Resource Analysis

This study focuses only on the metal demand for renewable energy (generation and storage) and transport and does not consider other demands for these metals. However, it is expected that with the increase in renewable energy, renewable energy technologies will consume a greater share of these metals and it is anticipated that this growth will have significant influence on overall market dynamics, including influencing prices, which may feedback to efforts to reduce material intensity and invest in reuse and recycling infrastructure.

Promoting the transition to circular economy for both renewable energy and resource cycles; and adopting a systems view that considers available supply as well as social and environmental factors is critically important. To support sustainable development goals, both the primary and secondary sources of the resources required to underpin this renewable energy transformation needs to be stewarded as the supply chains develop. The high total demand requirements for energy metals, demonstrates the importance of redesigning technologies and systems to eliminate the adverse social and environmental supply chain impacts, to promote long-life products, and to actively encourage efficient material use in both energy and transport sectors.

13.2 Policy Recommendations by Sector

To implement the 2.0 °C or 1.5 °C Scenario will require a significant shift in current policies. This section documents the policy measures that have been assumed for the scenarios presented in the previous chapters, as well as policy measures known to be successful. The global legal frameworks and regulations differ significantly on national and community levels. Therefore, only the functions and aims of suggested policy measures can be discussed, but not how they can be integrated into current jurisdictions. That said, it is assumed that the Paris Agreement will be the global basis.

13.2.1 Energy

The energy sector is not a homogeneous sector but is highly diverse. Therefore, policy measures can follow different strategies and can address different aspects and stakeholders. The supply side can be divided into the main sub-sectors of electricity, heating, and fuel supply. The demand side can be broken down further into buildings, industry, and transport. However, because all these sub-sectors are directly or indirectly connected via resources and energy markets, policy interventions can have different effects.

The basic principles for the development of the 2.0 °C and 1.5 °C Scenarios derive from the long-term experiences with scenario development of the authorship team, and have led to a ‘seven-step logic’.

This logic extends from the definition of the final state of the energy systems in the long-term future to the key drivers of the energy demand and the energy efficiency potentials, a technological analysis of supply and demand and the market development potential, and the specific policy measures required to implement a theoretical concept in the real market-place.

The seven steps are:

1. Define the maximum carbon budget and other targets, milestones, and constraints to achieve the climate goal;
2. Define the renewable energy resource potentials and limits within a space-constrained environment;

3. Identify the economic and societal drivers of demand;
4. Define the efficiency potentials and energy intensities by energy service and sector;
5. Establish time lines and narratives for the technology implementation on the end-user and supply sides;
6. Estimate the infrastructure needs, generation costs, and other effects;
7. Identify the required policies and discuss the policy options.

13.2.1.1 General Energy Policies

The energy sector requires both very specific measures, such as grid codes and efficiency standards, and overarching measures. International collaboration and co-operation are required to define and implement mandatory standards and to effectively develop energy policy and its regulative interventions. The most important interventions to accelerate the energy transition are:

- Renewable energy targets and incentives for their deployment and expansion;
- Internalization of external costs by carbon tax or surcharge;
- Phase-out of fossil fuel subsidies;
- Accelerated replacement of fossil and inefficient technologies.

Renewable energy targets are vital to accelerate the deployment of renewable energy. Experiences of the past two decades clearly show the effectiveness of renewable energy policy development. The Renewable Policy Network for the 21st Century (REN21) states in their annual market analysis, Renewables 2018, that "Targets remain one of the primary means for policy makers to express their commitment to renewable energy deployment. Targets are enacted for economy-wide energy development as well as for specific sectors" (REN21-GSR-2018). To achieve these goals, innovation processes must be initiated, markets developed, and investment stimulated. For the latter, auctions and feed-in tariffs have proven suitable. It is important in this context to guarantee investment security and to enable long-term but appropriate revenues.

Climate change leads to a number of types of environmental damage. Carbon emissions lead to climate change. Therefore, it is vital to put a price on carbon to internalize the external costs. Carbon-pricing schemes can be established as *cap-and-trade* schemes or taxes. Carbon pricing is not sufficient on its own to achieve the objective of the Paris Agreement, and many leading international agencies and institutions argue that a much more concerted and widespread global take-up of carbon pricing will be necessary (Carbon Tracker 2018). To make carbon pricing an efficient measure, the price of carbon must be sufficient to reflect the environmental damage it causes and it must be reliable. Therefore, a minimum price should be implemented to provide planning security.

Subsidies of fossil fuels counteract any efforts to make energy efficiency and renewable energy competitive. According to the International Energy Agency, the total amount of global fossil fuel subsidies was estimated to be around US$260 billion in 2016 (IEA-DB 2018). The governments of the G20 and the Asia-Pacific Economic Cooperation (APEC) reached an agreement to "*rationalize and phase out over the medium term inefficient fossil fuel subsidies that encourage wasteful consumption*" (OECD-IEA 2018).

Setting legally binding national targets for 100% renewable energy pathways will lead to an orderly phase-out of fossil fuels. This is vital in planning the socio-economic effects of the energy transition (see Chap. 10). Supporting measures to achieve the replacement of fossil and inefficient technologies and energy sources will be necessary because targets and economic incentives may not be sufficient in all areas. Regulatory interventions for the decommissioning and replacement of facilities are a way to stop opposing business scenarios and to overcome the inertia of consumers and investors. Moreover, economic policy measures and the clearer definitions and stringent enforcement of international standards will accelerate the implementation of the best available technologies in the industry.

Both a minimum price on carbon and the immediate phase-out of fossil fuel subsidies must be implemented in order to support the global energy transition. Policy support for technology innovation is another important measure to create the basis for the energy transition processes.

13.2.1.2 Policies for Buildings Sector Decarbonisation

To reduce the energy demands of existing building stock and new buildings, constantly most stringent energy demand standards (= *building energy codes*) are required for all building types and across all countries. The goal must be to achieve (near) zero-energy buildings, so that each building reduces its heating and cooling demand to the lowest possible level and aims to supply the remaining energy with on-site renewable energy technologies, such as solar collectors, electric heaters, advanced bioenergy and heat pumps, or with low-temperature heating networks. Mandatory municipal heating plans are an appropriate way to define an efficient strategy that balances insulation, local heating systems, and the grid-connected heat supply in regions with a significant space-heating demand. An analysis of building energy codes in 15 countries (Young 2014) distinguished between residential and commercial buildings and listed six technical requirement categories, ranging from heating and cooling requirements and the insulation of the building envelope to the building design. However, building energy codes must be mandatory and include existing building stock as well as new buildings. The most urgent need for action is in developing countries, where the rapid growth in building construction can be expected over the next decades. Economic measures to increase heating/cooling costs, e.g., by introducing fossil energy taxes or surcharges or by phasing-out fossil fuel subsidies, could support efforts to save energy. However, they must be accompanied by social policies.

13.2.1.3 Policies for more-Efficient Electrical Appliances

To reduce the electricity demand of consumer goods in households and equipment in buildings, the efficiency standards for electrical appliances, all forms of information and communication technologies (computers, smart devices, screens, televisions, etc.), white goods (washing machines, dryers, dishwasher, fridges, and freezers), electrical building equipment for thermal comfort, and lighting technologies are required. These efficiency standards must be dynamic and designed to support competition for the most efficient design. The Japanese front runner system (IEA-PM 2018) is a positive example of dynamic efficiency standards. Labelling programmes and purchase subsidies for the best available technologies can support the replacement of old devices with the most efficient technologies. Measures for training and capacity building are also essential, most importantly in non-OECD countries.

13.2.1.4 Policies for the Transport Sector

As well as resolute electrification and further technical advances in all transport modes, decision-makers in politics and the urban planning context must carefully steer transport habits and infrastructure development toward a climate-friendly transport system. Their aim should be to promote the use of less ecologically problematic transport modes. This can be done by, for example, the introduction of fiscal and regulatory measures that effectively reduce the subsidization of currently untaxed and internalisation of external costs.

In parallel, environmentally less harmful transportation modes should be incentivized. Investments must also be channelled towards highly productive and energy-efficient passenger and freight railway systems and towards a dense network of battery recharging and hydrogen refuelling infrastructures for road vehicles. In the passenger car and truck context, direct subsidies or tax incentives for electric vehicles will speed up the electrification of fleets. CO_2 taxation, road tolls, and congestion charges could be applied, in addition to parking-space management schemes to reduce road traffic and thus internal combustion engines in a transition to car-reduced cities. The assignment of parking lots and driving lanes exclusively to electric cars will speed the phase-out of internal combustion engines.

In aviation, measures could include the taxation of jet fuel and CO_2, the application of an emission trading scheme on the direct and indirect climate effects of flight at high altitudes. Direct and indirect public subsidies for carriers and airports should be abolished (investment and operational grants should be reduced and funding should be allocated to a competitive and attractive rail system).

All measures curtailing the use of individual passenger transport should be accompanied by the promotion of ubiquitous, fast, comfortable, and price-competitive public transport systems, ride and car sharing and on-demand services (especially for less densely populated semi-urban and rural areas). Last but not least, an attractive and safe infrastructure for bicycles and e-bikes will help to reduce emissions and other unwanted side-effects of transport. In this arena, Copenhagen and Amsterdam are at the cycling forefront and inspiring more and more cities in following their path. Cities must also curtail tendencies to urban sprawl and 'reinvent' the compact city ideal, which means becoming pedestrian-friendly cities, thus reducing the need for motorized individual mobility and freeing up space for recreation and green spaces.

Cities in developed countries should aim to transform their transport systems (often) from passenger-car-centred urban structures and policies towards pedestrian-, bike-, and mass-transport-friendly environments. The often densely populated emerging megacities in the upcoming economic powerhouses of Africa, Latin America, and Asia should invest, right from the start, in resilient public-transport-oriented urban structures instead of relying too strongly on individual passenger car traffic, as the OECD countries have done in the past.

13.2.1.5 Policies for the Industry Sector

Policies to achieve the implementation of new highly efficient technologies and to replace fossil fuel use in industry must be defined region-wide or even on the global level, and will require stringent and regulatory implementation. Economic incentives, national initiatives, and voluntary agreements with industrial branches will most probably not, by themselves, see the achievement of a rapid technological change. Concrete standards and requirements must be defined at a very detailed level, covering as far as possible all technologies and their areas of application. The systematic implementation of already-identified best-available technologies could begin in the next few years. Mandatory energy management systems should be introduced to identify efficiency potentials and to monitor efficiency progress. The sustainability features along process chains and material flows must also be taken into account when designing political measures. Particular attention must be paid to the material efficiency of both production processes and their products, because this can open up major energy efficiency potentials and reduce other environmental effects. Public procurement policies and guidelines can help to establish new markets and to demonstrate new more-efficient products and opportunities. The effectiveness of policy interventions must be assessed by independent experts and the further development of efficiency programs and measures will require ongoing coordination by independent executive agencies. The public provision of low-interest loans, investment risk management, and tax exemptions for energy-efficient technologies and processes will significantly support technological changes and incentivize the huge investments required. Knowledge transfer between sectors and countries can be achieved through networks initiated and coordinated by governments. Public funding for research and development activities with regard to technological innovation, low-carbon solutions, and their process integration will be vital to push the technological limits further. Innovative approaches to the realization of material cycles and recycling options, the recovery of industrial waste heat, and low-carbon raw materials and process routes in industry must also be identified and implemented.

13.2.1.6 Political Framework for Power Markets

The 2.0 °C and 1.5 °C Scenarios will lead to 100% renewable electricity supply, with significant shares of variable power generation. The traditional electricity market framework has been developed for central suppliers operating dispatchable and limited dispatchable (‘*base load*’) thermal power plants. The electricity markets of the future will be dominated by variable generation without marginal/fuel costs. The power system will also require the built-up and economic operation of a combination of dispatch generation, storage, and other system services whose operation will be conditioned by renewable electricity feed-ins. For both reasons, a significantly different market framework is urgently needed, in which the technologies can be operated economically and refinanced. Renewable electricity should be guaranteed priority access to the grid. Access to the exchange capacity available at any given moment should be fully transparent and the transmission of renewable electricity must always have preference. Furthermore, the design of distribution and transmission networks, particularly for interconnections and transformer stations, should be guided by the objective of facilitating the integration of renewables and to achieve a 100% renewable electricity system.

To establish fair and equal market conditions, the ownership of electrical grids should be completely disengaged from the ownership of power-generation and supply companies. To encourage new businesses, relevant grid data must be made available from transmission and distribution system operators. This will require establishing communication standards and data protection guidelines for smart grids. Legislation to support and expand demand-side management is required to create new markets for the flexibility services for renewable electricity integration.

Public funding for research and development is required to further develop and implement technologies that allow variable power integration, such as smart grid technology, virtual power stations, low-cost storage solutions, and responsive demand-side management. Finally, a policy framework that supports the electrification and sector coupling of the heating and transport sectors is urgently needed for a successful and cost-efficient transition process.

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