United Nations E/2020/60

Economic and Social Council

Distr.: General
8 May 2020

Original: English

2020 session
25 July 2019–22 July 2020
Agenda item 5 (b)
High-level segment: high-level policy dialogue on future trends and scenarios and the long-term impact of current trends on the realization of the 2030 Agenda for Sustainable Development

Long-term future scenarios and the impact of current trends on the realization of the Sustainable Development Goals

Report of the Secretary-General

Summary

The present report serves to inform the high-level segment of the Economic and Social Council scheduled for July 2020 and to complement the report of the Secretary-General entitled "Accelerated action and transformative pathways: realizing the decade of action and delivery for sustainable development" (E/2020/59). Decisions currently being taken in the context of the coronavirus disease (COVID-19) pandemic, as well as with regard to new Internet applications and artificial intelligence, may have implications in the long run on humanity's capacity to deal with major global challenges. Building on such trends, the report examines a global transformative best-case scenario pathway to achieve the Sustainable Development Goals and advance sustainable development by 2050 and contrasts it with business-as-usual and worst-case scenarios.

I. Introduction

1. In accordance with General Assembly resolution 72/305, the final day of the high-level segment of the Economic and Social Council, following the ministerial segment of the high-level political forum, will focus on future trends and scenarios related to the Council theme, the long-term impact of current trends, such as the contribution of new technologies, in the economic, social and environmental areas on the realization of the Sustainable Development Goals, based on the work of the United Nations and other regional and international organizations and bodies as well as other stakeholders. It should aim at enhancing knowledge-sharing and regional and international cooperation. The present report serves to inform the high-level policy dialogue on future trends and scenarios and the long-term impact of current trends on the realization of the 2030 Agenda for Sustainable Development, which is to convene on 17 July 2020. It complements and builds on the report of the Secretary-General entitled "Accelerated action and transformative pathways: realizing the decade of action and delivery for sustainable development (E/2020/59).

2. The report sets out a number of best-case, aspirational long-term scenarios with regard to the Goals and contrasts them with business-as-usual and worst-case scenario outcomes for 2030 and 2050. It also explores the consequences of the coronavirus disease (COVID-19) pandemic, as well as of new Internet technologies and artificial intelligence. Current and near-term decisions in both of those areas are expected to strongly influence capacity and the options available for dealing with other major sustainability challenges that humanity faces in the long run.

3. The 2030 Agenda outlines a broad and aspirational vision for people, the planet and prosperity (see General Assembly resolution 70/1, preamble). The Goals and targets therein provide a quantitative and qualitative snapshot of what the world would like to achieve by 2030. It also sets out selective targets for other years and outlines policy recommendations and actions, but does not include precise guidance on the feasibility of carrying out coordinated actions over time to achieve the Goals. That is what scenarios are designed to explore. They are internally consistent and plausible paths describing developments in the future. They coherently bring together scientific and technical knowledge from all relevant disciplines and sources to improve the understanding of possible future developments and support decision-making and planning about the future. Policymakers often refer to scenarios as pathways and this is synonymous with the terminology used in the present report.

4. However, scenarios are neither predictions nor forecasts.[1] Since the future is uncertain, scenario analysts need to make assumptions about underlying system dynamics and scenario drivers, uncertain scientific relationships, technology, policy and behavioural change. They use various techniques to deal with complex systems when asking "if … then …?" questions, in order to say something consistent about plausible future developments. Scenario analysis is therefore sometimes said to be more art than science. It focuses attention on identifying and testing feasible solutions to the world's main future challenges. Those solutions do not go beyond physical, technical, economic or sociopolitical boundaries, but truly make sense and are grounded in the best science and evidence available.

5. The scenario presented herein is a best-case scenario, also referred to as a low-energy demand (LED) scenario or a better futures scenario.[2] It is a consistent and

[1] Nebojša Nakićenović and others, *Special Report on Emission Scenarios* (Cambridge, United Kingdom of Great Britain and Northern Ireland, Cambridge University Press, 2000).

[2] Arnulf Gruebler and others, "A low energy demand scenario for meeting the 1.5°C target and Sustainable Development Goals without negative emission technologies", *Nature Energy*, vol. 3, No. 6 (June 2018).

highly aspirational scenario inspired by the latest technological developments, behavioural change and high-impact business innovations. The scenario explores what is needed now and in the coming years to achieve the Goals by 2030 and to advance sustainable development by 2050. Several scenario variants are highlighted in order to indicate the potential for alternative routes and decisions. The best-case scenario is compared with a business-as-usual scenario, which is based on the continuation of present trends and current policies in the future, as well as with a worst-case scenario, which highlights key risks and important decision points. The substantive scope of the scenarios follows that of the Goals but leaves out a number of institutional, governance and social issues that are hard to quantify but remain part of the overall storyline. Table 1 provides an overview of scenarios developed by some of the world's leading scenario modelers.[3]

Table 1
Overview of scenarios

	Scenario 1: best-case scenario	*Scenario 2: business-as-usual scenario*	*Scenario 3: worst-case scenario*
Scenarios described in the present report	LED and better futures scenario.	The middle-of-the-road scenario with a nominal 4.5W/m^2 radiative forcing level of the Shared Socioeconomic Pathway scenarios (SSP2-4.5) and the current trends scenario of the Food and Land Use Coalition.	The fossil-fuelled development scenario (SSP5-8.5) and the regional rivalry scenario (SSP3) of the Shared Socioeconomic Pathway scenarios.
Related variants	Nexus scenario of the Netherlands Environmental Assessment Agency; the 1.5°C and roads from Rio scenarios; and the International Energy Agency's *World Energy Outlook* sustainable development scenario.	The International Energy Agency's *World Energy Outlook* stated policies scenario.	
Scenario rationale	Rapid transition driven by extremely high end-use efficiencies, behavioural change and business innovations in energy, water and land use, fuelled by new information and communications technologies (ICTs).	Continuation of current trends, practices and technological change and the implementation of stated policies (e.g. measures against greenhouse gases in accordance with the nationally determined contributions).	Fragmented world unable to deal with its larger global challenges.
Assumptions	An interconnected world focused on science, technology and education, global diffusion of technology, open science and a common ambition to achieve sustainable development.	Continuation of current governance systems and the continuation of rapid technological progress alongside large socioeconomic and technological divides.	Fragmentation and collapse of the multilateral system, with barriers for gaining access to knowledge and technologies.

[3] More details can be found in the respective academic journals in which they have been published. They also build on and/or were featured in the eminent assessment reports such as the *Global Energy Assessment: Toward a Sustainable Future*, and reports of the Intergovernmental Panel on Climate Change, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services, the International Resource Panel and The World in 2050 initiative.

	Scenario 1: best-case scenario	*Scenario 2: business-as-usual scenario*	*Scenario 3: worst-case scenario*
Aspects related to COVID-19	Reinforced global cooperation, engagement in science and technology and a quick end to the pandemic and recovery.	Mainly national responses and lingering effects until 2021.	Major protracted health disaster and economic depression.
Aspects related to artificial intelligence	Many high-efficiency applications balanced with energy sufficiency considerations.	Many useful applications but an increasing energy demand and environmental impact from artificial intelligence. Energy use for artificial intelligence competes with other uses of energy.	Fewer artificial intelligence solutions emerge and quickly hit energy limits. Artificial intelligence highly concentrated in few countries. No significant efficiency improvements with regard to energy and materials.
Results in 2030	Achievement of the Goals.	Progress made in the achievement of the Goals, but major gaps remain.	Progress in few areas and regression in others.
Results in 2050	Sustainability of a high-tech and interconnected world.	Significant.	Major sustainable development disasters.

Sources: Gruebler and others, "A low energy demand scenario", including extensive supplementary information, see https://doi.org/10.1038/s41560-018-0172-6; Riahi and others, "The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview", *Global Environmental Change*, vol. 42 (January 2017); Food and Land Use Coalition, *Growing Better: Ten Critical Transitions to Transform Food and Land Use* (2019); Detlef P. van Vuuren and others, "Pathways to achieve a set of ambitious global sustainability objectives by 2050: explorations using the IMAGE integrated assessment model", *Technological Forecasting and Social Change*, vol. 98 (September 2015); Detlef P. van Vuuren and others, "Alternative pathways to the 1.5°C target reduce the need for negative emission technologies", *Nature Climate Change*, vol. 8, No. 5 (May 2018); Detlef P. van Vuuren and others, "Integrated scenarios to support analysis of the food–energy–water nexus", *Nature Sustainability*, vol. 2, No. 12 (December 2019); and International Energy Agency, *World Energy Model* (Paris, 2019). Their data are available from the International Institute for Applied Systems Analysis, LED database, available at https://db1.ene.iiasa.ac.at/LEDDB (presenting data published in Gruebler and others, "A low energy demand"; and the Shared Socioeconomic Pathways databases from the International Institute for Applied Systems Analysis (see https://tntcat.iiasa.ac.at/SspDb), the Netherlands Environmental Assessment Agency and the International Energy Agency.

II. Current trends and scenario wild cards

6. There are a number of current and pervasive long-run trends that will significantly shape the future. The scenario drivers include population and demographic trends; increasing prosperity, better health and quality of life; rapid urbanization in the developing world, in particular in mid-size cities; novel infrastructure services; decentralization that allows new end user roles (from consumers to producers, innovators and traders); and ICT innovation. Along similar lines, the report of the Secretary-General on accelerated action and transformative pathways: realizing the decade of action and delivery for sustainable development (E/2020/59) sets out selected trends and elements of transformative pathways in some of the entry points for action, as proposed in the *Global Sustainable Development Report 2019*.[4] These are all extremely important elements for understanding long-run scenarios for the Goals. However, there are two areas in which decisions taken in the

[4] Independent Group of Scientists appointed by the Secretary-General, *Global Sustainable Development Report 2019: the Future is Now – Science for Achieving Sustainable Development* (New York, United Nations, 2019).

short term will probably have decisive consequences on the feasibility of long-run future pathways: with regard to the COVID-19 pandemic and with regard to new Internet applications and artificial intelligence.

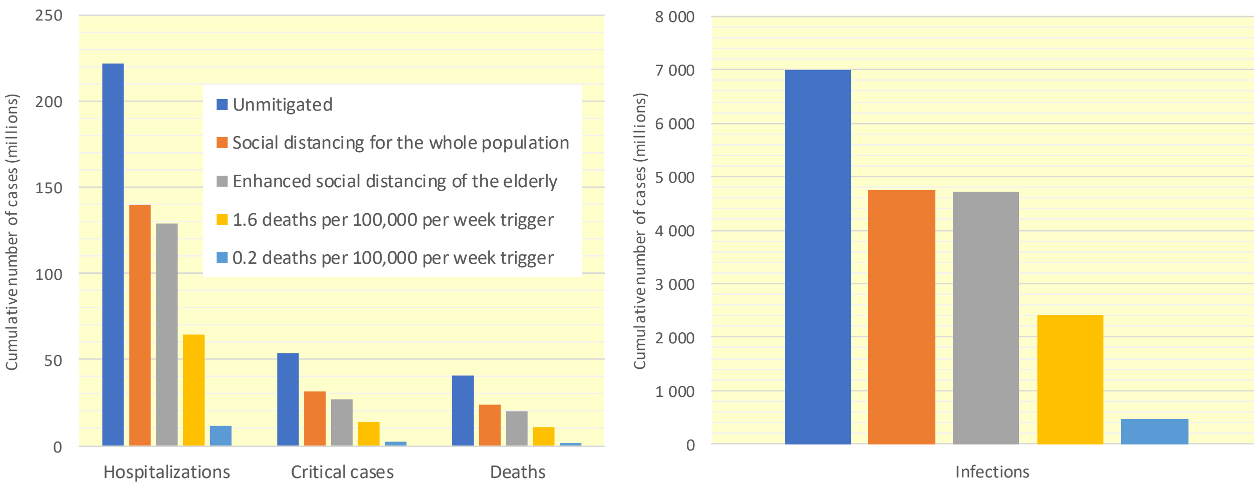
Coronavirus disease pandemic

7. On 11 March 2020, the World Health Organization declared the COVID-19 outbreak to be a pandemic. As at the time of writing, 22 April 2020, events have unfolded rapidly and the pandemic has had an impact on every country on the planet. More than 2.6 million people have tested positive for the virus, at least 180,000 people have died and 720,000 have recovered. Owing to insufficient testing and reporting, the true numbers of infections and deaths are likely to be much higher, with infections worldwide likely to be one to two orders of magnitude higher, according to statistical estimates. That would mean that anywhere between 20 million and 200 million people are likely to have already been infected. According to epidemiological model results, millions might die in the coming months, with anywhere between 1.9 million and 40 million fatalities by the end of the pandemic, depending on the policy measures that are taken (see figure I). There might be several waves of infection until either wide-scale vaccination becomes available or herd immunity is achieved.[5]

8. About 2.6 billion people, one third of the global population, were in lockdown at the beginning of April 2020 and more than 100 countries had closed their borders, which had a severe economic impact on them. Tens of millions of jobs have already been lost and the world economy is expected to enter a deep recession (see the policy brief series of the Department of Economic and Social Affairs and the report of the Secretary-General entitled "Accelerated action and transformative pathways: realizing the decade of action and delivery for sustainable development" (E/2020/59)). Scientific and technological capabilities mean that there is no doubt that humanity will ultimately defeat the novel coronavirus. However, it remains unclear how the pandemic itself and its socioeconomic impact will play out in the coming months and to what extent the unprecedented socioeconomic and policy measures taken in the midst of this crisis will determine the world's future pathways in the long run and potentially constrain its capacity to deal with sustainability risks. Indeed, the response to the pandemic appears to be a wild card. Humanity is at a branching point at which it will either opt for closer international collaboration or for a weakening of the current system of international cooperation. Figure I shows the cumulative number of infections, hospitalizations, critical cases and fatalities resulting from five short-term COVID-19 choices, leading to the three long-term scenarios described further below.

[5] Patrick G.T. Walker and others, "The global impact of COVID-19 and strategies for mitigation and suppression", 26 March 2020.

Figure I
Global cumulative number of infections, hospitalizations, critical cases and fatalities by the end of the coronavirus disease pandemic



Source: Department of Economic and Social Affairs, illustrating estimates reported in Walker and others, "The global impact of COVID-19".

Note: The figure shows the cumulative numbers of infections, hospitalizations, critical cases requiring treatment in an intensive care unit and fatalities by the end of the pandemic for five epidemiological scenarios involving the following social distancing policy measures:
(1) Unmitigated: no action is being taken;
(2) Social distancing for the whole population: measures are taken to uniformly reduce the rate at which individuals come into contact with one another by around 45 per cent, short of complete suppression of epidemic spreading;
(3) Enhanced social distancing of the elderly: identical to scenario (2) but with individuals aged 70 years or more reducing their social contact rates by 60 per cent;
(4) and (5) Suppression of epidemic spreading: wide-scale intensive social distancing measures (modelled as a 75 per cent reduction in interpersonal contact rates) are being taken with the aim of rapidly suppressing epidemic spreading and minimizing near-term cases and deaths whenever 1.6 deaths or 0.2 deaths per 100,000 people per week are reached, respectively.
Considerable scientific uncertainty remains about the contagiousness of the virus, measured as R0, for which a best-guess estimate of 3 was used in the calculations. In other words, without policy interventions, each infected individual would infect three other individuals. Estimates for R0 range from 2.4 to 3.3, which gives a fatalities range of 35 million to 42 million for scenario (1), 20 million to 26 million for scenario (2) and 12 million to 22 million for scenario (3).

9. COVID-19 scenario 1 (best-case scenario): in this scenario, the crisis is seen as a wake-up call that leads to more effective global cooperation and greater engagement of scientific and technological communities to defeat the virus, as scientific knowledge and economic resources jointly target humanity's common enemy. As a result, a first vaccine becomes available in September 2020 and is rapidly manufactured and distributed globally to the majority of the world population. Economic recovery is quick in the latter half of 2020, buttressed by strengthened global cooperation and effective scientific and technological advisory systems that are increasingly leveraged to address other key global health and sustainability challenges. Trust in science is high and the top-performing technologies become accessible worldwide.

10. COVID-19 scenario 2 (business-as-usual scenario): in this scenario, there is continued global cooperation among the existing institutions, but in times of crisis, the focus is on national responses, most of which remain uncoordinated among each other. Policymakers continue to consider scientific evidence and technological possibilities, but policies vary greatly across Governments and societies and are often limited in scope. Other collaborations across scientific and technology communities grow in response, holding promise for enhanced cooperation in the future, but many remain underresourced and on a small scale. Various COVID-19 vaccines are made

available by the first or second half of 2021. A global vaccination programme ultimately defeats the virus in 2021, opening the way for economic recovery. However, various transport restrictions remain and businesses and Governments become increasingly cautious about the resilience of global supply chains, potentially leading to a less globalized world and one in which public and shared transport and dense settlements become less acceptable options.

11. COVID-19 scenario 3 (worst-case scenario): in this scenario, the current crisis leads to a perception of the multilateral system as increasingly irrelevant. Responses are at the national level and in an uncoordinated fashion, with Governments competing over health equipment and economic resources. Vaccines become available by 2021 in a number of countries but might not be accessible to many. Transport and travel restrictions are lifted only slowly, with some remaining in place. In the absence of actions to stimulate effective globally coordinated economic recovery, a global economic depression is likely, resulting in an international community that lacks the capacity and willingness to jointly address the major global challenges facing humanity in the future.

New technologies, Internet applications and artificial intelligence

12. The fast pace of technological change in recent years in robotics, artificial intelligence, biotechnology, nanotechnology and related areas, such as big data, is having a broad impact on the economy, society and the environment. At the heart of these trends are telecommunications and ICTs. On the one hand, these emerging technologies hold great promise for the development of high-efficiency energy and water systems that could be deployed in all countries to catalyse global sustainability. On the other hand, despite efficiency increases, these technologies, especially artificial intelligence, will require ever-increasing electricity and mineral resources and cause associated pollution and waste (e.g. e-waste, nano-waste and chemical waste), including to fuel many entirely new services. When fundamental limits to increased energy efficiency of silicon-based computing are also considered, it is evident that additional applications that do not enhance efficiency will continue to increase energy demand unless strict sufficiency considerations or limitations on energy use are introduced.

13. The best-guess estimate of the entire energy used by the global Internet in 2019 is about 2,000 TWh or 7.2 exajoules, which is equivalent to about 9 per cent of total global electricity use. Roughly half of that total, or 966 TWh, accounts for consumer devices, such as computers, mobile phones, laptops and televisions. The remaining 1,022 TWh accounts for local, fixed and mobile networks, data centres and the manufacture of various components. Excluding consumer devices, the latter category alone caused emissions of about 949 million tons of carbon dioxide in 2019. The mobile network component, in particular, is expected to increase rapidly with the advent of the fifth generation technology standard for cellular networks (5G) and the increasing use of mobile video streaming services. Video streaming alone accounts for annual carbon emissions equivalent to those of the whole of Spain.[6] The short product life cycle of electronic products such as smartphones and computers is the reason for the large amount of electronic and electrical waste that the world produces every year. In 2017, the energy production footprint of all smartphones in the world was about 30 per cent higher than that of all passenger cars.[7] Currently, as much as 50 million tons of e-waste is produced annually, which is a larger weight than that of all commercial aircraft ever built, and only 20 per cent of that waste is formally recycled.

[6] Maxime Efoui-Hess, “Climate crisis: the unsustainable use of online video – the practical case for digital sobriety”, July 2019.

[7] Vaclav Smil, *Energy and Civilization: a History* (Cambridge, Massachusetts, the MIT Press, 2018).

14. Moore's law refers to a statement made in 1965 that the number of transistors in a dense integrated circuit would double about every two years – a relationship that has held true for 50 years, driving exponential performance improvements in electronics. Dennard scaling is a law formulated in 1974, according to which, as transistors become smaller, their power density stays constant, so their power use stays in proportion to their area. Moore's law and Dennard scaling have allowed manufacturers of central processing units to increase clock frequencies from one generation to the next without significantly increasing overall circuit power consumption. Since around 2012, a slowdown of Moore's law and Dennard scaling has been observed, and, as a result, general-purpose microprocessors are not becoming faster or more energy-efficient at the same rate.[8] Through ingenious designs, however, the performance of supercomputers has continued to improve along an exponential path. By 2014, the fastest supercomputer for the first time surpassed 20 petaflops in computing speed, which is roughly the hardware-equivalent of the human brain.[9] It reached a peak performance of 201 petaflops, which is equivalent to approximately 10 brains, at the end of 2019, and could be equivalent to 500 brains by 2025, 10,000 brains by 2030 and 700,000 brains by 2040. The total annual electricity consumption of the fastest supercomputers has rapidly increased each year, from 12.6 GWh in 2006 to 88.4 GWh in 2019, even though energy efficiency has improved by a factor of 10 every five years. That is why supercomputers have rapidly emerged as significant contributors to world energy consumption.[10]

15. Deep-learning neural networks, the most successful artificial intelligence technology currently in use, are highly data- and computing-intensive. A state-of-the-art deep-learning neural network model for facial recognition in 2019 required an estimated 656 MWh for the training phase, resulting in 313 tons of carbon dioxide emissions.[11]

16. Other areas in which current decisions may have an outsized influence on future long-term possibilities are with regard to new Internet applications and artificial intelligence. All sustainable development scenarios necessarily rely on reining in overall energy and materials use through a combination of rapidly increasing efficiencies in production and energy use and behavioural change in favour of energy sufficiency. However, recent trends bring into question the circumstances under which such a balance can be achieved in the long run. The energy demand of Internet applications and artificial intelligence, as well as the associated greenhouse gas emissions, which were both relatively low in the past, are already significant and continue to increase unabated. Those technologies are key to smart energy systems and to increasing overall energy efficiency. Nevertheless, new technologies will also continue to bring about entirely new services, most of which are not geared towards improving efficiency and will hence further increase global energy demand. The energy efficiency of ICTs has reached fundamental limits, while overall computing performance and usage continues to increase unabated. The energy efficiency of current silicon-based computing is estimated to be at least four to five orders of magnitude lower than that of the human brain. The most likely result of these trends will be an acceleration and increase in the energy demand of Internet applications and artificial intelligence, unless sufficiency considerations fundamentally change the current direction.

---

[8] Vivian Sze, "Efficient computing for AI and robotics", MIT lecture, May 2019.

[9] According to the Flow Genome Project founder, Steven Kotler. See Peter H. Diamandis and Steven Kotler, *Bold: How to Go Big, Create Wealth and Impact the World* (New York, Simon and Schuster, 2015).

[10] R. Roehrl, "Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system", Technology Facilitation Mechanism research paper, December 2019.

[11] Emma Strubell, Ananya Ganesh and Andrew McCallum, "Energy and policy considerations for deep learning in NLP", 5 June 2019.

17. The overall effect of Internet and artificial intelligence technologies on global energy and materials use in the coming years remains highly uncertain and will depend on technology choices, standards, and efficiency and sufficiency policy choices. Not surprisingly, best-guess estimates for overall ICT energy use in 2030 show an extremely wide range of values, from 2,067 to 8,265 TWh.[12] This uncertainty was also reflected in a recent survey of experts which showed that the majority of experts and scenario analysts expect an increase in global energy demand over and above the dynamics-as-usual trends by 2030. A minority of respondents (20 per cent) expected a decrease and almost one third (30 per cent) highlighted uncertainty factors.[13]

18. Artificial intelligence scenario 1 (best-case scenario): in the best-case scenario, the full range of new technologies and artificial intelligence becomes available, increasing the overall efficiency of energy and materials use and providing new solutions to many challenges at the cost of only moderately increased energy consumption. This depends on disruptive innovations continuing to rapidly increase the energy efficiencies of artificial intelligence and computing, despite the fact that Moore's law no longer applies.

19. Artificial intelligence scenario 2 (business-as-usual scenario): similar to scenario 1, a wide range of new solutions become available, albeit at the cost of rapidly increasing ICT energy use, with corresponding environmental consequences and widely unequal access to the new technologies. Artificial intelligence energy use increasingly starts competing with other energy uses.

20. Artificial intelligence scenario 3 (worst-case scenario): in this scenario, fewer artificial intelligence solutions emerge and those that do quickly hit their energy limits. Artificial intelligence is highly concentrated in only a few countries and, as a result, few countries benefit significantly from artificial intelligence and there is no dramatic change in the efficiency of global energy and materials use.

III. Long-term scenarios for the achievement of the Sustainable Development Goals and beyond

21. Ever since the Rio+20 Conference in 2012, many scenario modellers have developed global sustainable development scenarios and, since 2015, more scenarios specifically related to the Goals. Those scenarios focus on economic, technological or political approaches. In the past eight years, however, unabated global increases in the use of energy, materials and land, together with associated environmental, social and health consequences, have led analysts to explore ever more ambitious scenario assumptions concerning the achievement of the Goals in the fewer and fewer years that remain before 2030.

22. To take Goal 13 on climate action as an example, greenhouse gas emissions would need to be reduced by 7.6 per cent per year until 2030, compared with a reduction of only 3.3 per cent per year if decisive action had already been taken 10 years ago.[14] To achieve such an ambition, many scenario analysts have assumed that as yet unproven technological fixes, such as bioenergy with carbon capture and storage, will result in a decrease in emissions on a large scale, especially 30 years from now. Not only are there issues with the logistics of safely storing billions of tons of carbon dioxide every year, there are also issues related to the large-scale use of land for biocrops.

[12] Anders S.G. Andrae, "Drawing the fresco of electricity use of information technology in 2030: part II", February 2019.

[13] R. Roehrl, "Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system".

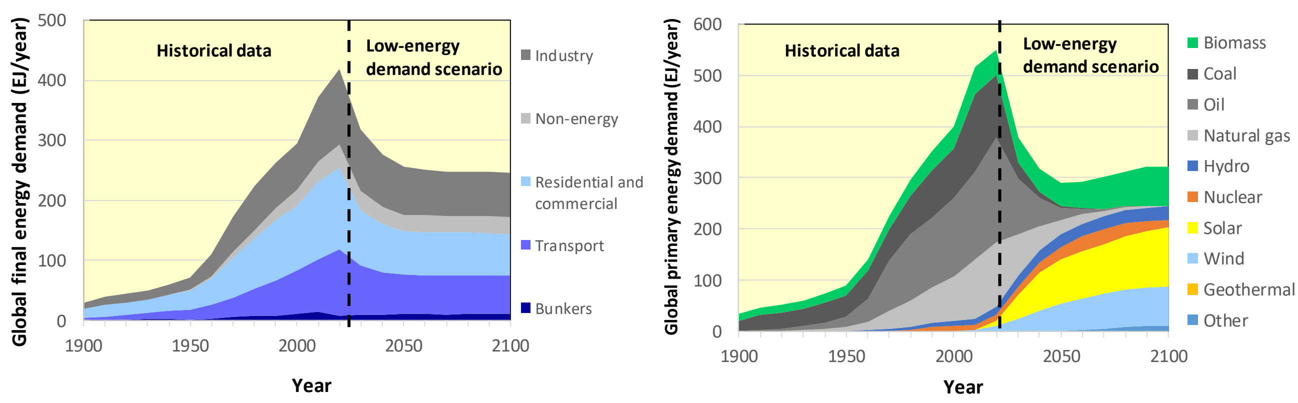
[14] United Nations Environment Programme (UNEP), *Emissions Gap Report 2019* (Nairobi, 2019).

Best-case scenario: “LED better futures”

23. Against that background, in 2018, several eminent scenario analysts and scientists took a different approach and designed a scenario that aims for exceptional progress on Goal 12, related to sustainable consumption and production, through a rapid transition to lower primary use and high-efficiency end-use technologies and practices for energy, water, land and materials. With regard to a global low energy demand or LED scenario,[15] consistent and detailed scenario implementations were developed for land use and food (the better futures scenario),[16] water[17] and other sectors of the Goals. The resulting LED better futures scenario provides important benefits in relation to all the Goals.

24. In the LED scenario, the 1.5°C climate target and the Goals are met without relying on negative emission technologies, such as bioenergy with carbon capture and storage, thereby sparing hundreds of millions of hectares of cropland. Most importantly, by 2050, global final energy demand would be only 245 exajoules,[18] which is 40 per cent lower than today, despite increases in population, income and economic activity. In fact, this is known as the lowest long-run final energy demand scenario in the peer-reviewed literature. However, the lower final demand does not come at the expense of energy services, which instead continue to increase to levels assuring decent standards of living for all. At the global level, services in this scenario would be well above access and poverty thresholds and well above those of many other scenarios, achieved through radical improvements in efficiencies. In other words, services and end-use devices would become vastly more efficient over the next 10 years. The result is that peak energy would be reached by 2020 and rapid electrification would be achieved (see figure II). Current rates of renewable energy deployment would suffice to meet future energy needs. End-use transformations would drive upstream decarbonization, as the much smaller size of the global energy system would make it significantly easier to achieve low-carbon supply-side transformation. Table 2 provides an overview of key scenario parameters.

Figure II
Global primary and final energy demand in the LED scenario



Source: Gruebler and others, “A low energy demand scenario”. Historical data comes from the International Institute for Applied Systems Analysis Primary, Final and Useful Energy database. (Simon De Stercke, “2014 Dynamics of energy systems: a useful perspective”, IR-14-013, July 2014).

---

15 Gruebler and others, “A low energy demand scenario”.

16 Food and Land Use Coalition, *Growing Better*.

17 Simon Parkinson and others, “Balancing clean water-climate change mitigation trade-offs”, WP-18-005, May 2018.

18 Excluding an additional 10.5 exajoules for international bunkers (used by international maritime and air transport).

25. In the LED scenario, almost half of the reduction in energy demand by 2050 would be accounted for by decisions to adopt technology,[19] and the other half by behavioural change.[20] Between 2019 and 2030, annual global investment of about $45 billion (twice the amount invested in the business-as-usual scenario) would be needed to achieve universal energy access, mostly for access to electricity. That would amount to less than 2 per cent of the total annual investment in the energy sector. In the LED scenario, overall energy supply investment requirements for fuel systems, power plants and networks would increase only slightly by 2030 and decrease thereafter because in the coming decade, the required increase in investment in the power supply would be about as large as the expected reduction in the investment in fuel systems. However, investment in energy end use, such as appliances and services, as well as in related business opportunities, would rapidly expand. While the publication of the LED scenario does not provide comprehensive investment figures for end use and services, the *World Energy Outlook*, published by the International Energy Agency, which has a similar focus on end use in the sustainable development scenario, provides further insight: in the 2019–2050 period compared with the 2014–2018 period, annual investment in fuel and power systems is expected to increase from $1.71 trillion to $1.92 trillion, and from $0.37 trillion to $1.64 trillion for energy end use, resulting in total energy investment increasing from $2.08 trillion to $3.56 trillion per year. However, much of the investment in end-use efficiency would ultimately benefit consumers through lower costs for electricity and fuel.[21]

Table 2
Comparison of the LED better futures scenario with the business-as-usual scenario

	Today	*LED scenario*		*Business-as-usual (SSP2-4.5)*		
Category	*2020*	*2030*	*2050*	*2030*	*2050*	*Unit*
Population	7.6	8.3	9.2	8.3	9.2	billion
Gross domestic product (purchasing power parity)	101	143	231	143	231	trillion $2010/year
Gross domestic product (market exchange rates)	71	109	197	Not available	Not available	trillion $2010/year
Energy supply investment	1.17	1.25	1.05	Not available	Not available	trillion $2010/year
Final Energy	410	309	245	509	618	exajoules/year
Primary Energy	551	378	289	645	771	exajoules/year
Agricultural Production	4.1	4.7	5.9	5.4	6.9	billion tons dry matter/year
Food Demand	2 905	2 985	3 130	Not available	Not available	kcal/capita/day
Carbon dioxide emissions	39.6	16.2	2.7	43.5	43.5	gigatons carbon dioxide/year
Radiative forcing	2.7	2.9	2.7	3.0	3.7	W/m^2
Water consumption	2.4	2.4	2.3	Not available	Not available	1 000 km^3/year

Source: International Institute for Applied Systems Analysis, LED and Share Socioeconomic Pathways databases.
Note: Primary energy is calculated using the physical energy content approach.

26. The LED scenario explores new social, behavioural and technological innovations, including high-performance innovations at the fringes of current markets. The scenario shows what could feasibly be achieved by increasing the energy

[19] For example, in high-efficiency vehicles and appliances.
[20] For example, with regard to shared mobility, public transport and building insulation.
[21] International Energy Agency, "Abstract", in International Energy Agency, *World Energy Model*.

efficiency in building, transportation and consumer goods manufacturing, leading to two- to four-fold increases in overall eco-efficiencies.[22]

Table 3
Transformation of end-use services and upstream sectors in the LED scenario for the period 2020–2050

		Activity levels	*Energy intensity*
End-use services	*Thermal comfort*	Roughly constant in the global North and a 35 per cent increase in the global South, converging on a global average of 30m^2/capita.	High service-efficiency thermal end-use technologies, combined with a doubling of the retrofit rate in the global North and new building standards in the global South, reduces energy intensity by 75 per cent in the global North to around 160–170 megajoules/m^2 and by 86 per cent in the global South to 40 megajoules/m^2.
	Consumer goods	Doubling in the global North to 42 devices per capita; tripling in the global South to 24 devices per capita.	Fall in global average electricity intensity, weighted by share of total devices, from 93 to 82 kWh per device, with the biggest reductions in lighting and appliances.
	Mobility	Doubling across all modes of transport (in particular, flexible route-sharing vehicles) in the global South; 20 per cent fall in the global North, with larger reductions in road-based modes offsetting increases in rail and air usage.	70 per cent fall in global average energy intensity weighted by modal share, with the strongest reductions in road-based modes of transport as a result of electrification, shared fleets, flexible public transit and active modes.
	Food	Increase of food demand of between 70 and 100 per cent globally, combined with the continuation of dietary transition. Food availability is resolved in the global South, with populations achieving the appropriate calorie intake.	Not available
Intermediate and upstream sectors	*Commercial and public buildings*	An increase of 43 per cent to 23m^2/capita in the global North and an increase of 50 per cent to 9m^2/capita in the global South.	Falls of 76 per cent to an average of 139 megajoules/m^2 in the global North and of 90 per cent to an average of 44 megajoules/m^2 in the global South.
	Industry	Demand for global commodities (steel, aluminium, cement, paper, petrochemicals and feedstock) falls by around 15 per cent to 6.4 gigatons, one third as a result of dematerialization and two thirds as a result of improvements in materials efficiency.	Global average energy intensity, weighted by the share of activity of specific manufacturing and construction processes, falls by one fifth to 16.7 gigajoules/ton.

[22] United Nations, "The clean energy technological transformation", in *World Economic and Social Survey 2011: The Great Green Technological Transformation* (United Nations publication, Sales No. E.11.II.C.1).

	Activity levels	Energy intensity
Freight transport	Increases by around 20 per cent in the global North to 64 trillion ton-kilometres and by around 70 per cent in the global South to 58 trillion ton-kilometres, with larger increases in rail and shipping and some reductions in truck activity.	Global average intensity falls by 50 per cent to between 0.5 and 0.7 megajoules/ton-kilometres for trucks and by 10 per cent to 0.2 megajoules/ton-kilometres for rail. Limited potential for electrification in shipping and aviation, so no significant intensity changes.

Source: Gruebler and others, "A low energy demand scenario".

27. In this scenario, ICT in general, and artificial intelligence in particular, have applications in and an impact on almost all aspects of the global energy system, including energy supply (mining and production), power plants and utilities, final distribution and end user devices, thereby accelerating technological progress. Table 3 provides a quantitative summary of the major transformations of end-use services and upstream sectors. The reductions in energy demand achieved in all sectors are so large that they would vastly outweigh associated increases in the energy demand for artificial intelligence. For example, shared and on-demand fleets of more energy-efficient electric vehicles with increased occupancy could reduce global energy demand for transport by 60 per cent by 2050. That is much more than the 3 per cent increase in power demand from computing in a typical self-driving passenger car prototype.[23] Intelligent smartphones could nudge preferences towards services and away from ownership. Energy performance standards of buildings could reduce energy demand from heating and cooling by 75 per cent by 2050. Artificial intelligence could support the integration of intermittent modern renewable energy sources, such as wind and solar power, and reduce energy storage needs. Low-meat diets could reduce agricultural emissions while increasing forest cover. The scenario also implicitly assumes hardware design innovations in artificial intelligence chips and robotics that would continue to significantly increase their energy efficiency, despite the fact that Moore's law would no longer apply. The scenario developers detailed energy and emissions reduction potential for 99 innovations in energy, mobility, food, buildings and cities.[24]

28. Renewed efforts in research and development, technology diffusion and infrastructure investment could lead to higher yields, increasing resource productivity. Combined with regenerative farming practices, reduced food loss and waste, dietary shifts towards less resource-intensive proteins and the protection of and payment for the ecosystem services provided by forests, oceans and soils, food systems would greatly benefit the environment, biodiversity, oceans and local livelihoods and contribute to the reduction of rural poverty. Enough food would be produced in 2030 to deliver on Goal 2 to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. The LED better futures scenario fares vastly better than the business-as-usual scenario (see table 4).

[23] Self-driving car prototypes typically use 2.5 kW of computing power, compared with 75 kW for a typical car with a 100 hp engine. Cameras and radar alone generate about 12 GB of data per minute. Some prototypes require water cooling (*Wired Magazine*, February 2018).

[24] Charlie Wilson and others, "The potential contribution of disruptive low-carbon innovations to 1.5°C climate mitigation", *Energy Efficiency*, vol. 12, No. 2 (February 2019).

Table 4
Land, food, biodiversity and oceans in the LED better futures scenario compared with the business-as-usual scenario

	Low-energy demand better futures		*Business-as-usual*		
	2030	*2050*	*2030*	*2050*	
Deforestation	0.2	0.2	7.6	6.7	Million ha/year
Change in agricultural land	(475)	(1 200)	200	400	Million ha (v. 2010)
Restored natural land	450	1 300	100	225	Million ha (v. 2010)
Food insecure people	0	Not available	475	Not available	Million
Biodiversity intactness index	(0.6)	0.2	(1.8)	(3.2)	% v. 2010
Death due to high body mass index	4.0	5.6	6.4	10.1	Million people/year
Food and land use emissions	4.7	0	12	13	Gigatons of equivalent carbon dioxide/year
Oceans: mariculture of bivalves	Not available	80	Not available	3	Million metric tons
Oceans: wild catch	Not available	24%	Not available	(15%)	Increase v. 2010

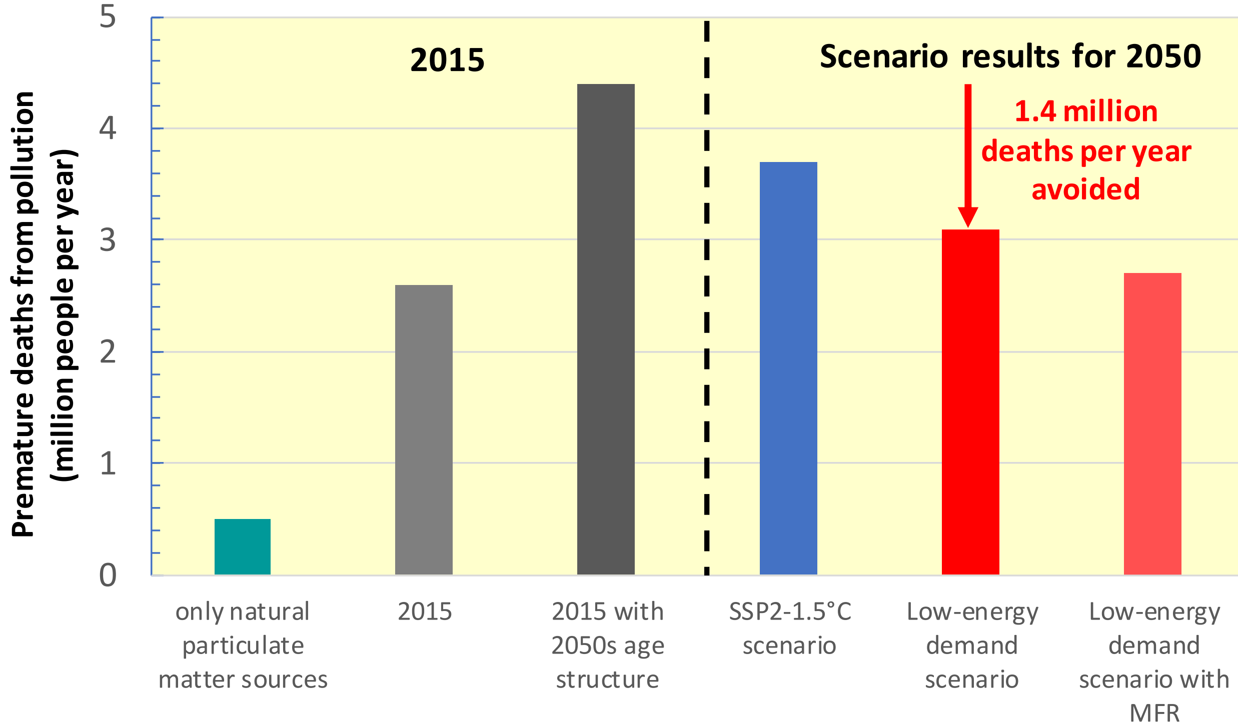
Source: Food and Land Use Coalition, *Growing Better*.

29. A higher aggregate agricultural productivity (1.1 per cent per year), reduced food loss and waste (minus 25 per cent by 2050) and dietary shifts (with oceans providing 40 per cent more protein by 2050) would allow more than 1.5 billion hectares of land to be converted from agricultural use, compared with the business-as-usual scenario. In the coming decade, negligible levels of conversion of forests and other natural ecosystems are in principle possible, but immediate action would be needed before 2025. The additional social benefit of reducing greenhouse gas emissions in this scenario is estimated at an enormous $1.3 trillion per year, mainly in relation to protecting and restoring tropical forests. Biodiversity declines would be reversed already by the end of the 2020s. Changes to demand and production methods in the coming years would erode the advantages of high-intensity agriculture, reducing the overuse of fertilizers, herbicides and pesticides. Healthier diets could reduce the number of people dying prematurely from diet-related weight and obesity problems from over 10 million to less than 6 million by 2050.

30. The stakes are high, in view of the fact that the hidden health, environmental and economic costs of the global food and land use systems totalled $11.9 trillion in 2018, which was $1.9 trillion more than the entire market value of the global food system of $10 trillion. The LED better futures scenario would reduce the costs to $5.5 trillion in 2050, compared with an increase to $16.1 trillion in the business-as-usual scenario.[21] An increase in investment of 0.3 per cent of global gross domestic product, equivalent to $350 billion per year, in human capital, technologies and the food and land use systems could provide annual health, environmental and economic gains of $5.7 trillion by 2030 and $10.5 trillion by 2050. It could double the growth of rural incomes compared with current trends and create an additional 120 million decent jobs.

31. A reduction in the amount of ambient air pollution (defined as fine particles with a diameter of 2.5 micrometres or less) could prevent 1.4 million premature deaths per year by 2050 compared with a continuation of current practices, and could prevent about 1 million premature deaths per year compared with the middle-of-the-road scenario variant (SSP2) that achieves the same 1.5°C climate target but otherwise follows the business-as-usual assumptions described in the present report (see figure III). Such a large reduction is expected to particularly benefit the poor, who are most exposed to air pollution.

Figure III
Premature deaths from ambient air pollution (fine particles with a diameter of 2.5 micrometres or less) in 2015 and in selected scenarios by 2050



Source: Gruebler and others, "A low energy demand scenario".
Abbreviations: MFR, maximum feasible emissions reductions with near-term technology; SSP2-1.5°C, business-as-usual scenario but with the ambitious climate policy to achieve 1.5°C temperature stabilization.

32. Closely related variants of the LED better futures scenario provide an idea of alternative pathways for achieving the Goals, should one or the other of the ambitious assumptions not be realized. For example, researchers, including from the Netherlands Environmental Assessment Agency, proposed a scenario for the Goals which is similar to the LED scenario, whereby the 1.5°C target is achieved, including with rapid electrification in the end-use sector, but also including some use of bioenergy with carbon capture and storage and the bending of the curve towards sustainability through lifestyle changes rather than technology.[25] The most recent Nexus scenario is fully integrated and explores changes to diets, agricultural efficiency, climate policy, biodiversity and the water supply and illustrates a much-reduced energy and resource system.[26] The "roads from Rio" scenario dates back to the Rio+20 Conference but includes detailed quantifications of many of the goals that later became the Sustainable Development Goals.[27] Another scenario explores the maximum global cropland-sparing potential of high-yield farming. It concludes that cropland requirements could be reduced by almost 40 per cent, even if 20 per cent of cropland is released for landscape elements and cropland in biodiversity hotspots is spared.[28]

[25] Van Vuuren and others, "Alternative pathways to the 1.5°C".
[26] Ibid., "Integrated scenarios to support analysis".
[27] Ibid., "Pathways to achieve a set of ambitious global sustainability objectives by 2050".
[28] Christian Folberth and others, "The global cropland-sparing potential of high-yield farming", *Nature Sustainability*, vol. 3, No. 4 (April 2020).

Comparison with business-as-usual scenario

33. Many elements of the business-as-usual scenario have been presented as a contrast to the LED better futures scenario described above. In the business-as-usual scenario, significant progress is made in the achievement of the Goals, but major gaps remain in 2030. The scenario is based on the assumed continuation of current trends, practices and technology change and the implementation of stated policies.

34. For the energy sector, the business-as-usual scenario is similar to the policy scenario set out by the International Energy Agency in its *World Energy Outlook*. The typical business-as-usual scenarios chosen for the present report were the SSP2 scenario, which entails a set of middle-of-the-road scenarios used by the Intergovernmental Panel on Climate Change. In particular, the data presented is from the SSP2-4.5 integrated scenario variants in which it is assumed that all greenhouse gas emission reduction measures contained in the nationally determined contributions under the Paris Agreement, whether conditional or non-conditional, are actually implemented in the future. The SSP2-4.5 scenario roughly corresponds to the conditional scenario regarding nationally determined contributions described in the *Emissions Gap Report 2019* of UNEP, in which an average temperature increase of 3.2°C above pre-industrial levels is expected, primarily because of the very large size of the global energy system.

35. The average aggregate agricultural productivity continues increasing at 0.9 per cent per year, which would be insufficient to rein in continued biodiversity loss (minus 3.2 per cent until 2050 according to the biodiversity intactness index), or to eradicate food insecurity. However, rapid technological progress continues and major socioeconomic and technological divides persist, with that progress exacerbating the gap in some areas and in other cases closing it.

36. Human ingenuity would drive the supply and demand for entirely new technology and artificial-intelligence-based services, many of which would not enhance energy efficiencies but further increase the size of the global energy system. Mobile video streaming, for example, requires significant energy use (e.g. the system that delivers YouTube videos consumed 21 TWh in 2019) and next-generation 5G mobile networks would greatly increase the energy and climate footprint of online video streaming, as would new video gaming streaming.[29]

Comparison with worst-case scenarios

37. Worst-case scenarios and their environmental and socioeconomic implications are described in detail in leading environmental assessment reports, including the reports of the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services and the *Global Environment Outlook* of UNEP. The fossil-fuelled development scenario (SSP5-8.5)[30] used in the report of the Intergovernmental Panel on Climate Change would likely lead to catastrophic climate change with repercussions on all sectors and socioeconomic areas. The regional rivalry scenario (SSP3)[31] would lead to a fragmented and poor world, with slow economic development, material-intensive consumption, worsening inequalities and a high population. Which of the two scenarios is considered worse lies in the eye of the beholder. Both have in common that they describe a world that is not cooperating effectively and is unable to deal

[29] Chris Preist, Daniel Schien, and Paul Shabajee, "Evaluating sustainable interaction design of digital services: the case of YouTube", in Association of Computing Machinery, *Proceedings of 2019 CHI Conference on Human Factors in Computing Systems* (2019).

[30] Elmar Kriegler and others, "Fossil-fuelled development (SSP5): an energy and resource intensive scenario for the 21st century", *Global Environmental Change*, vol. 42 (January 2017).

[31] Riahi and others, "The shared socioeconomic pathways".

with its larger global challenges. In one scenario, the multilateral system would become irrelevant, whereas in the other, it would be dysfunctional. Both scenarios are characterized by conflict. While there would be significant technological progress, barriers to gaining access to knowledge and technologies would persist or worsen. As a result, the few areas in which progress has been made with regard to sustainable development would quickly be undone by regression in other areas, likely leading to major sustainability disasters.

IV. Issues for consideration

38. The following issues should be considered to support policymaking in the context of a successful decade of action to complement the policy issues for consideration proposed in the report of the Secretary-General entitled "Accelerated action and transformative pathways: realizing the decade of action and delivery for sustainable development" (E/2020/59):

(a) Consider the long-term sustainable development implications of current decisions in response to and in support of recovery from the COVID-19 pandemic and prioritize those that increase resilience to future crises;

(b) Consider the long-term sustainable development implications of policies, plans and programmes related to new Internet applications and artificial intelligence, with a view to balancing energy efficiency and sufficiency considerations;

(c) Facilitate and prioritize investment in and coordinated actions on technology efficiency, business innovation and behavioural change to rapidly increase end-use efficiency, as inspired by the LED better futures scenario;

(d) Strengthen international cooperation on scientific and technological solutions for the Goals;

(e) Promote actor coalitions with urban citizens and farmers and consider systemic incentives, especially related to land use, transport and infrastructure;

(f) Encourage businesses to explore new opportunities through service-oriented business models, increased efficiency, granular end use and technological innovation;

(g) Encourage the United Nations system to provide coordinated capacity-building support for the development of national scenarios related to the Goals and to engage with scientists and technologists, including to support preparations for voluntary national reviews;

(h) Bring scenario analysts, scientists and frontier technology experts together as part of the Technology Facilitation Mechanism to share their experience and technology foresight and to synthesize the latest knowledge on sustainable development and on the impact of new technologies on the Goals;

(i) Institute a regular exchange between scenario analysts, government science advisers and decision makers on high-impact actions for sustainable development.