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Long-term future trends and scenarios: impacts in the economic, social and environmental areas 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 to be held in July 2021 and to complement the report of the Secretary-General (E/2021/62) on the theme of the 2021 session of the Council and the 2021 high-level political forum on sustainable development (see General Assembly resolution 74/298). On the one hand, the pandemic has caused an acceleration in digitalization; on the other, it has significantly amplified persistent technology divides, essentially excluding billions of people from reaping the benefits of digital technologies and innovations. There is large untapped potential for digital consumer innovations in the contexts of mobility, food, buildings and energy services, which could be readily deployed worldwide at a level commensurate with the global best-case scenario identified in the previous report (E/2020/60). These innovations could radically transform global service efficiencies, opening up more feasible pathways everywhere towards the achievement of the Sustainable Development Goals, good living standards and the agreed climate-related goals. However, the vast majority of financial stimulus packages produced in response to the pandemic have not yet been focused on longer-term measures and sustainable investments. The present report contains proposals for cooperative, near-term actions aimed at transforming service efficiencies that are commensurate with a sustainable and resilient recovery from the pandemic, promoting the economic, social and environmental dimensions of sustainable development and building an inclusive and effective path for the achievement of the 2030 Agenda for Sustainable Development in the context of the decade of action and delivery for sustainable development.

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I. Introduction

1. The present report serves to inform the high-level segment of the Economic and Social Council, to be convened from 13 to 16 July 2021, on future trends and scenarios and the long-term impact of current trends on the realization of the 2030 Agenda for Sustainable Development.[1] The report provides a long-term perspective towards 2030 and beyond and thus complements the report of the Secretary-General (E/2021/62) on the theme of the 2021 session of the Council and the 2021 high-level political forum on sustainable development, as set out in see General Assembly resolution 74/298.

2. The 2030 Agenda for Sustainable Development, as set out in General Assembly resolution 70/1, reflects a broad, aspirational vision for people, planet and prosperity. The Sustainable Development Goals and targets set out therein provide a quantitative and qualitative snapshot of what the world would like to have achieved by 2030. The 2030 Agenda also contains targets for other years and provides an outline of policy recommendations and actions, but does not include precise guidance on the feasibility of carrying out coordinated actions over time to attain the Goals. That is what scenarios are designed to explore.

3. Scenarios are internally consistent and plausible paths that serve to describe developments in future contexts. In the present report, they are also referred to as "pathways", a term often used by policymakers. They reflect the scientific and technical knowledge coherently amassed from all relevant disciplines and sources, in order to foster a better understanding of possible future developments and support decision-making. Scenarios, however, are not predictions. Instead, scenario analysts make assumptions about an inherently uncertain future and use conditional statements ("if-then") in their reasoning. Scenarios serve to focus thinking on the identification of solutions that do not breach physical, technical, economic or sociopolitical boundaries but that truly add up and grounded in the best available science and evidence.

4. In his previous report (E/2020/60), the Secretary-General presented the low energy demand (LED) scenario ("LED better futures"), which is a best-case scenario for the achievement of the Goals and sustainable development by 2050. He highlighted what was at stake by providing a contrast between that scenario and prominent business-as-usual and worst-case scenarios. In particular, he considered the potential long-term consequences of near-term decisions in two areas: responses to the COVID-19 pandemic and to new Internet and artificial intelligence technologies. In the report, he suggested that actions in those two areas might strongly influence the capacity and available options to deal with other great sustainability challenges that humanity will be facing in the longer run. It is now opportune – one year later – to review the extent to which the world's past actions have been aligned with the low energy demand scenario and what can be done in the near term to get the world on this desirable pathway.

5. Further details are also provided in the present report on how the low energy demand scenario outperforms many other sustainable development scenarios, in terms of achieving the entire range of Sustainable Development Goals, in particular, in

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[1] In accordance with General Assembly resolution 72/305, the final day of the high-level segment of the 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 is aimed at enhancing knowledge-sharing and regional and international cooperation.

terms of achieving high living standards for everyone. The Secretary-General takes stock of the long-term impacts of current trends related to responses to COVID-19 and digitalization. He also outlines the potentially large benefits of a number of specific digital consumer innovations that could be deployed worldwide right now and proposes a set of concrete, near-term actions that could be undertaken, in developed and developing countries alike, to transform end-use efficiencies at a level commensurate with the Goals and climate target aspirations. He concludes the report with a section containing issues for consideration.

II. Low energy demand "LED better futures" scenario

6. Ever since the United Nations Conference on Sustainable Development was held in Rio de Janeiro, Brazil, in 2012, many scenario modellers have developed global sustainable development scenarios and, since 2015, have developed scenarios more specifically related to the Goals, emphasizing economic, technological or political approaches. However, in the past eight years, as a result of unabated increases in the use of energy, materials and land, together with associated environmental, social and health consequences, analysts have had to make ever more ambitious scenario assumptions to achieve the Goals in the fewer and fewer years that remain before 2030.

7. For example, in order to limit global warming to the 1.5°C target, 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, had decisive action been already taken 10 years ago.[2] For the sake of comparison, global carbon dioxide emissions declined by 6.4 per cent in 2020 owing to the COVID-19 crisis.[3] Successive reductions of this magnitude would be necessary every year for the entire decade to reach the goal. It is a formidable challenge.

8. In addressing the challenge, many scenario analysts have assumed yet unproven technological fixes, such as bioenergy with carbon capture and storage, to produce negative emissions on a large scale, especially 30 years from now. However, there are logistical issues not only with regard to the safe storage of billions of tons of carbon dioxide on an annual basis but also with large-scale land use for biocrops.

A new approach

9. Against that background, several eminent scenario analysts and scientists took a different approach in 2018 and designed an aspirational pathway inspired by the latest technological developments, behavioural change and high impact business innovations. The scenario was aimed at making exceptional progress with regard to sustainable consumption and production (Goal 12) through rapid transitions to lower energy demand and very high efficiency end-use technology and practices in energy, water, land and materials. The low energy demand scenario[4] meets the Sustainable Development Goals and the 1.5°C climate target without relying on unproven negative emissions technologies. As a result, hundreds of millions of hectares of cropland could be spared. The scenario was featured in the special report of the

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

[3] Jeff Toleffson, "COVID curbed carbon emissions in 2020 – but not by much", *Nature*, 15 January 2021.

[4] Arnulf Grubler 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).

Intergovernmental Panel on Climate Change entitled *Global Warming of 1.5°C*.[5] Based on the original energy scenario, consistent, detailed scenario implementations were developed for land use and food ("better futures" scenario),[6] water[7] and other sectors addressed in the Goals. The resulting, combined "LED better futures" scenario translates into important benefits in the context of all of the Goals. Related but somewhat different scenario variants have also been developed by the Netherlands Environmental Assessment Agency[8] and the International Energy Agency.[9] Scenario data are available in online databases.[10]

The big picture: achievement of the Goals and decent living standards

10. The key goal of the "LED better futures" scenario is to reduce overall global energy, water and land use, despite increases in population and economic activity and rapid increases in living standards. Achievement of this goal is possible owing to the large untapped potential for increasing end-use efficiencies through a combination of technological, behavioural and business innovations – a transition fuelled by information and communications technologies (ICTs).

11. The scenario features a world that becomes increasingly interconnected and focused on education, science and technology, that fosters the rapid diffusion of technology on a global scale and that leverages open science for sustainable development. Many digital technologies and artificial intelligence applications are deployed and service efficiencies are vastly increased. In what becomes a high-tech interconnected world, the Goals are achieved by 2030, and broader sustainability by 2050. In fact, the scenario is seen to outperform alternative scenarios in terms of progress towards achieving the Goals (see figure I). In the scenario, a rapid improvement in living standards in developing countries is shown to reach a level far beyond the basic services described in the Goals or so-called decent living standards (see figure II), essentially allowing for those countries to catch up with the developed world. At the same time, however, global use of energy and resources would decline.

[5] Valérie Masson-Delmotte and others, eds., *Global Warming of 1.5°C: an IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty* (Intergovernmental Panel on Climate Change, 2019).

[6] Food and Land Use Coalition, *Growing Better: Ten Critical Transitions to Transform Food and Land Use* (2019).

[7] Simon Parkinson and others, "Balancing clean water-climate change mitigation trade-offs", IIASA Working Paper, No. WP-18-005 (International Institute for Applied Systems Analysis, Laxenburg, Austria, 2018).

[8] 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); 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); and 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).

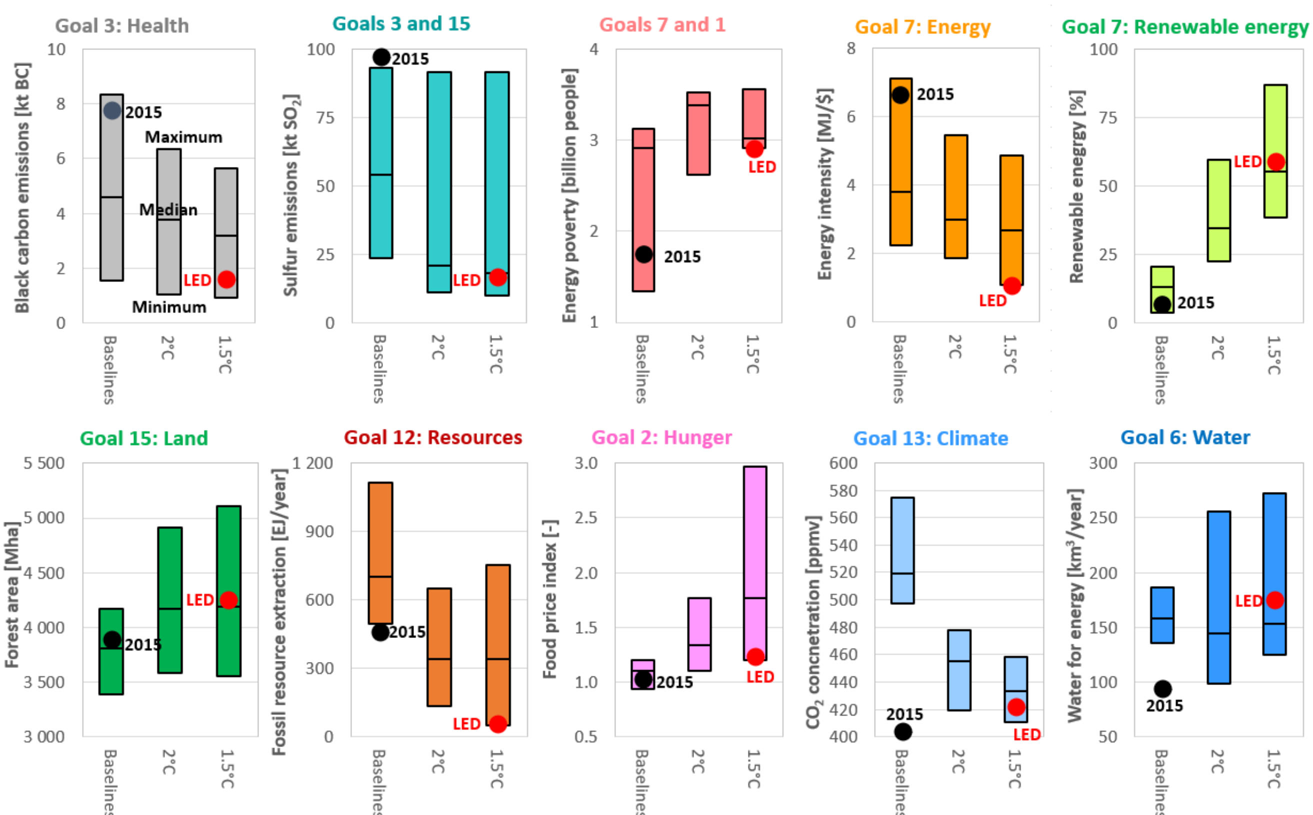
[9] International Energy Agency's (IEA) sustainable development scenario contained in the IEA World Energy Model – scenario analysis of future energy trends, *World Energy Outlook* (November 2019).

[10] International Institute for Applied Systems Analysis, Low Energy Demand database, available at https://db1.ene.iiasa.ac.at/LEDDB, as related to Grubler and others, "A low energy demand scenario for meeting the 1.5 °C"; and International Institute for Applied Systems Analysis, Shared Socioeconomic Pathways database, available at https://tntcat.iiasa.ac.at/SspDb, as related to Keywan Riahi and others, "The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview", *Global Environment Change*, vol. 42 (January 2017).

Decent standard of living requirements ensure that people flourish, including by having access to amenities that promote good health and quality of life and enable them to engage with society.[11]

12. Such outcomes would be achieved through overall strategies to electrify energy end use worldwide; to bring homes, appliances and transport modes to the technological efficiency frontier; to support multifunctionality through convergence of multiple services onto single devices or business models; to promote a generational shift from ownership of material goods to accessing services; to increase the utilization rates of goods, infrastructure and vehicles (sharing and circular economy); to promote user-oriented innovation; to ensure decentralization in allowing new roles for end users not just as consumers but also as producers, innovators and traders; and to achieve pervasive digitalization and rapid innovation in granular technologies.

Figure I
Sustainable Development Goals: comparing the performance of the "LED better futures" scenario with other prominent scenarios



Source: Adapted from figure 5.3 in Joyashree Roy and others, "Sustainable development, poverty eradication and reducing inequalities", in *Global Warming of 1.5°C*, Masson-Delmotte and others, eds. (Intergovernmental Panel on Climate Change, 2019).
Note: Ranges spanned more than 100 scenarios with the median indicated.

[11] Narasimha D. Rao, and Jihoon Min, "Decent living standards: material prerequisites for human well-being", *Social Indicators Research*, vol. 138, No. 1 (July 2018).

Figure II
Future living standards in developing countries: "LED better futures" scenario compared with "decent living standards" and current living standards scenarios

Sources: Grubler and others, "A low energy demand scenario for meeting the 1.5 °C target"; and Rao and Min, "Decent living standards: material prerequisites for human well-being".
Note: Per capita amounts. Household consumer goods include air-conditioning units, television sets, phones and appliances for cooking, refrigeration and washing.

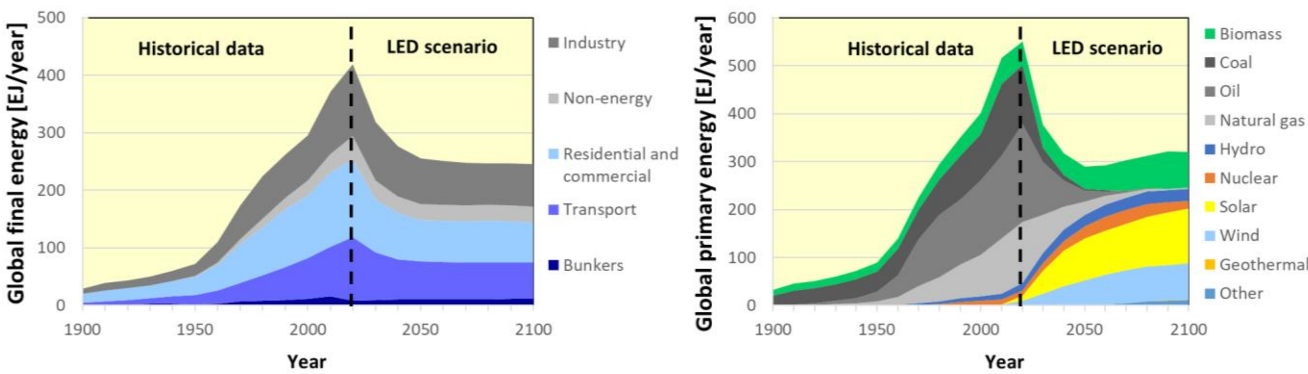
More detailed look at the "LED better futures" scenario

13. The idea underlying the scenario is to reduce the global energy footprint despite an increasing population, higher living standards and economic growth, which is key to sustainability. According to the scenario, by 2050, global final energy demand would be only 245 exajoules,[12] which is 40 per cent lower than it is today, despite increases in population, income and economic activity. However, the lower final demand does not come at the expense of energy services, which would continue to increase for all, because end-use devices and service provision 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 III). Current rates of renewable energy deployment would suffice to meet future energy needs. End-use transformations drive upstream decarbonization, as the much smaller size of the global energy system makes it significantly easier to achieve low-carbon supply-side

[12] Excluding an additional 10.5 exajoules in international bunkers (used in international maritime and air transport).

transformation. About half the reduction in energy demand until 2050 is due to technology,[13] the other half due to behavioural change.[14]

Figure III
Global primary and final energy demand in the "LED best futures" scenario



Sources: Grubler and others, "A low energy demand scenario" (2018): Historical data: Simon De Stercke, *Dynamics of Energy Systems: A Useful Perspective*, Interim Report, No. IR-14-013 (IIASA, Laxenburg, Austria, 2014); International Institute for Applied Systems Analysis, Primary, Final and Useful Energy database, available at https://tntcat.iiasa.ac.at/PFUDB/dsd?Action=htmlpage&page=welcome.

14. In the scenario, ever more services could be provided while less energy is used. For example, the residential floor space that is heated or cooled would converge worldwide to today's levels in developed countries, of about 30 m^2 per person (figure II). This would be achieved through a doubling of retrofit rates in developed countries to 3 per cent, the introduction of "Passivhaus" standards[15] for new buildings in developing countries and flexible use building design. According to the scenario, people in developing countries would enjoy an average of 27 consumer devices per household in the future, which is triple the number today, and more than in the developed world today. Energy intensity could improve on average by 15 per cent per device and as much as 70 per cent in lighting. Device convergence and a shift from ownership to usership would further increase energy service efficiencies. With regard to personal mobility, which would double in developing countries to almost 10,000 passenger-km per person per year, energy intensity would be reduced by a factor of 3 owing to electrification. Shared and responsive modes could increase vehicle occupancy by 25 per cent and daily usage by 75 per cent, which would imply a halving of the global vehicle fleet needs for a given unit of transport service. Such measures would contribute to accelerated progress in developing countries, enabling them to meet the goal of ensuring access to affordable, reliable, sustainable and modern energy for all.

15. A myriad social, behavioural and technological innovations, including high performing innovations at the fringes of current markets, are explored in the scenario, such as looking at what could feasibly be achieved in terms of energy efficiency (a two- to four-fold reduction) in buildings, transport and consumer goods manufacturing.[16] In addition, digitalization – in particular artificial intelligence – is

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[13] For example, high-efficiency vehicles, appliances.
[14] For example, shared mobility, public transport, building insulation.
[15] The Passivhaus standard is a set of voluntary criteria for an ultra-low energy use home. Originally developed in Germany for houses and low-rise multi-unit residential buildings, the standard has been applied to houses in a range of other countries and to commercial buildings as well.
[16] David O'Connor and others, "The clean energy technological transformation", in *World Economic and Social Survey 2011* (United Nations publication, Sales No. E.11.II.C.1).

expected to have impacts on almost all aspects of the global energy system, supply (mining and production), power plants and utilities, final distribution and end-user devices, thereby accelerating technological progress. The achieved energy demand reductions in all sectors are vastly larger than the increases in energy demand to run the underlying artificial intelligence system. 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. Such overall reduction dwarfs the 3 per cent increase in power demand from computing in a typical self-driving passenger car prototype.[17] Intelligent smartphones could nudge preferences towards services and against 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 renewables, such as wind and solar, and reduce energy storage needs. Low-meat diets could reduce agricultural emissions while increasing forest cover. The scenario implicitly also assumes hardware design innovations in artificial intelligence chips and robotics that would continue to significantly increase their energy efficiency.

16. Large-scale investments are needed to make the scenario a reality. Achieving universal energy access (Goal 7) is comparatively cheap and would require a doubling of current investments to an estimated $45 billion per year until 2030, most of it for electricity access. It would amount to less than 2 per cent of the total annual investment in the energy sector. Overall energy supply investment requirements for fuel systems, power plants and networks would increase only slightly until 2030 and would decrease thereafter because an increased investment in the power supply would be roughly offset by a lower need for investment in fuel systems. In contrast, investments in energy end use and services, and related business opportunities would rapidly expand. A rough estimate is that for the 2019–2050 period, compared with the 2014–2018 period, annual investment in fuel and power systems would need to increase from $1.71 to $1.92 trillion, and from $0.37 to $1.64 trillion for energy end use, resulting in total energy investments increasing from $2.08 to $3.56 trillion per year.[18] However, much of the end-use efficiency investments would ultimately benefit consumers through lower costs for electricity and fuel.

17. As demand and production methods change in the coming years, the advantages of high-intensity agriculture will be eroded, reducing overuse of fertilizers and herbicides/pesticides. In the coming decade, negligible conversion of forests and other natural ecosystems is in principle possible, but immediate action will be needed before 2025. As much as 1.5 billion hectares of land could be shifted away from agriculture (compared with the business-as-usual scenario). This could be achieved through a combination of investments in research and development and in infrastructure, raising agricultural productivity (by +1.1 per cent per year), and efforts to reduce food loss and waste (by -25 per cent by 2050) and to encourage a shift in diets, with oceans delivering 40 per cent more proteins until 2050. Such efforts would greatly benefit the environment and local livelihoods. Biodiversity declines are already being reversed in the 2020s. Enough food would be produced in 2030 to achieve Goal 2 to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. Healthier diets could also reduce the number of people dying prematurely owing to diet-related weight and obesity problems, from

[17] Self-driving car prototypes typically used 2.5kW of computing power, compared to 75kW of a typical car with 100HP engine. Cameras and radar alone generated about 12 GBytes of data per minute, with some prototypes requiring water cooling (source: *Wired Magazine*, February 2018).

[18] While the publication of the LED scenario does not provide comprehensive investment numbers for end use and services, the sustainable development scenario set out in the *World Energy Outlook* of the International Energy Agency has similar end-use focus and provides further insight. See www.iea.org/reports/world-energy-model/sustainable-development-scenario#abstract.

over 10 million to less than 6 million by 2050. The additional social benefit of reducing greenhouse gas emissions in the scenario is estimated at an enormous $1.3 trillion per year, mainly related to protecting and restoring tropical forests. In these respects, the scenario fares vastly better than the business-as-usual scenario.

18. Sustainable food systems are a key entry point for achieving the Sustainable Development Goals.[19] However, the stakes for transforming the global food system are high. In fact, 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 these costs to $5.5 trillion in 2050, compared with an increase to $16.1 trillion in the business-as-usual scenario.[20] Increased investment of 0.3 per cent of global gross domestic product (GDP), 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.

19. A reduction in the amount of ambient air pollution and fine particulate matter (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 about 1 million per year compared with the middle-of-the-road scenario variant (shared socioeconomic pathway No. 2 (SSP2)) that achieves the same 1.5°C climate target but otherwise follows business-as-usual assumptions. Such a major reduction is expected to particularly benefit the poor, who are most exposed to air pollution.

20. In brief, the "LED better futures" scenario charts a way towards a highly desirable sustainable future, with multiple benefits and the potential for preventing various global sustainability crises. With so much at stake, the world should closely assess its current policies and actions against this pathway.

III. Long-term impacts of current trends related to responses to the coronavirus disease (COVID-19) and digitalization

21. In his previous report, the Secretary-General argued that decisions being taken in response to COVID-19 as well as with regard to new Internet applications and artificial intelligence might have implications in the long run on humanity's capacity to deal with major global challenges. He also proposed best, worst and business-as-usual scenarios in those two areas.

Coronavirus disease (COVID-19) pandemic

22. The number of people infected remains highly uncertain. As at 15 April 2021, 141 million individuals had tested positive and 3 million deaths had been reported, despite the many restrictions and lockdowns that have affected billions since the start of the pandemic. As far back as October 2020, the World Health Organization had reported that an estimated 10 per cent of the world's population, or almost 800 million people, had been infected. Hence, it is highly likely that more than 1 billion people had been infected by April 2021. As at 24 April 2021, 1.01 billion vaccine doses had

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

[20] Arnulf Grubler and others, "A low energy demand scenario".

been administered, even though access to the vaccines has remained extremely unequal.[21]

23. While vaccination campaigns remain in "catch-up" mode with virus mutations owing to high infection rates, the rapid development of highly effective vaccines, the testing of vaccines in record time, as well as accelerated digitalization in many parts of the world, has been impressive. It remains to be seen if the global innovation system can be mobilized in the same manner to invent, innovate and deploy new technologies to address neglected tropical diseases, and environmental and other sustainable development challenges. It is also important to note that innovation aimed at achieving specific objectives has benefitted from earlier global cooperation in, for example, research and development and public funding for "vaccine platforms" and messenger ribonucleic acid (mRNA) technology.

24. The innovation acceleration that has taken place in the course of the current enduring crisis is reason for cautious optimism about possible innovation-driven solutions in other areas of sustainability concern, in line with what is envisaged in the "LED better futures" scenario. However, it is clear that there have also been many missed opportunities, especially in terms better global cooperation, global solidarity and trust in science. In fact, in a broad context, the world remains on a business-as-usual trajectory, as outlined in the previous report, in which the Secretary-General stated (E/2020/60, para. 10):

> In this scenario, there is continued global cooperation among the existing institutions, but in times of crisis the focus is on the 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 limited in scope. Other collaborations across scientific and technology communities have grown 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 will be less acceptable options.

25. One of the areas of concern is that the vast majority of financial stimulus packages produced in response to the pandemic have not yet focused on sustainable recovery and that the sheer size of the packages may crowd out possibilities for more sustainable investments and lead to increased adherence to following the business-as-usual pathway. According to the *Global Recovery Observatory* of the United Nations Environment Programme and the University of Oxford, there have been more than 3,000 spending policies in the 50 largest economies[22] since the beginning of the pandemic.[23] Out of a total of $14.6 trillion[24] in fiscal measures to address the crisis, $11.1 trillion was directed to immediate rescue efforts (to manage the short-term effects) and $1.9 trillion to longer-term recovery measures.[25] The total accounted for about 23 per cent of GDP of advanced economies in the sample and 11 per cent of

[21] Our World in Data, "Vaccinations", Coronavirus (COVID-19) database. Available at https://ourworldindata.org/covid-vaccinations (accessed on 24 April 2021).

[22] These comprise 26 emerging economies and developing countries ($31 trillion GDP) and 24 advanced economies ($51 trillion GDP).

[23] Oxford University Economic Recovery Project, Global Recovery Observatory database, available at https://recovery.smithschool.ox.ac.uk/tracking/.

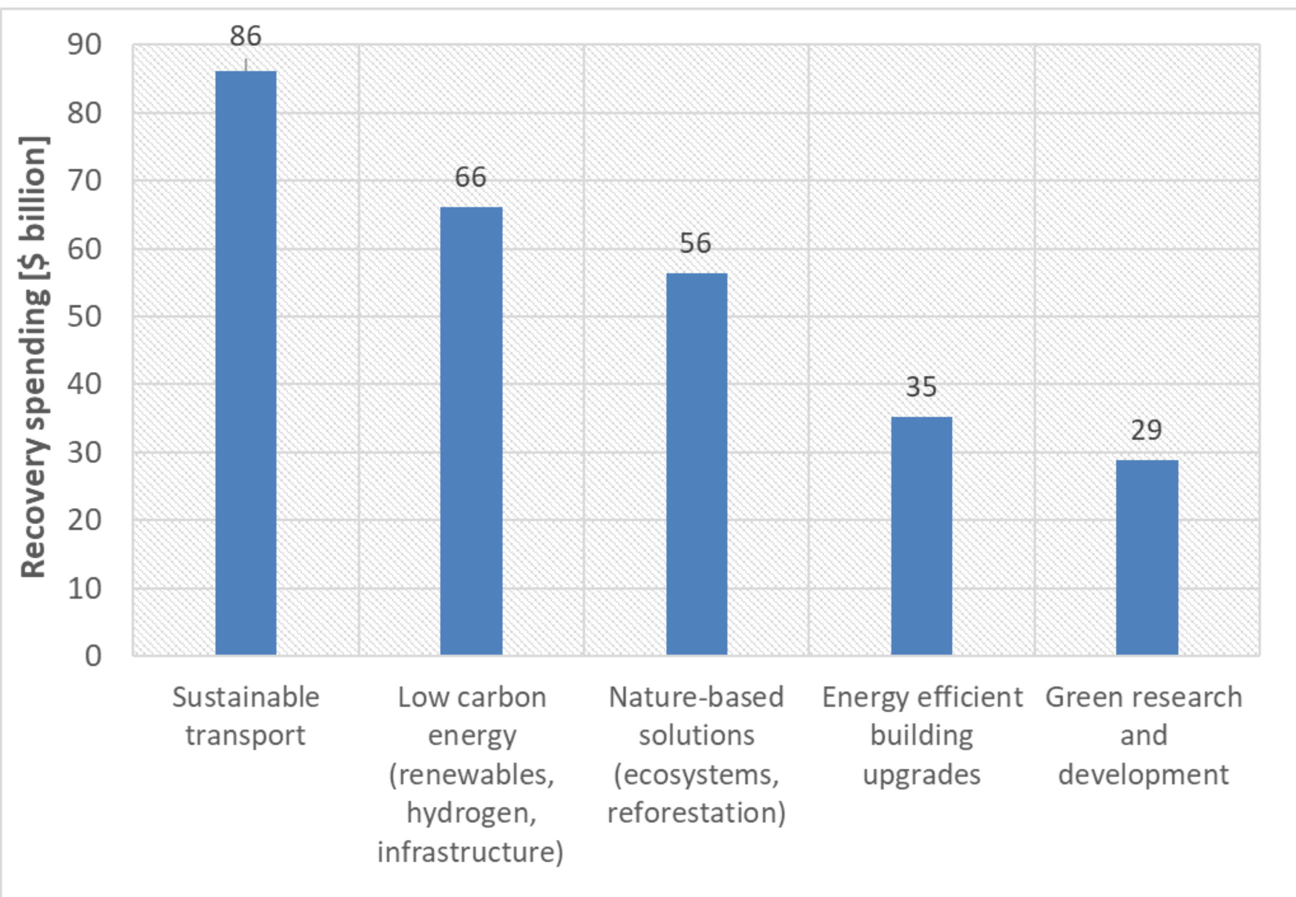
[24] $17 trillion with commitments by the European Commission.

[25] Another $1.6 trillion was recorded as unclear spending.

GDP of emerging market and developing economies in the sample. Of the recovery measures, only 18 per cent, or $341 billion, was identified as "green" or environmentally compatible spending. Almost all of the green recovery spending was in only seven countries (in descending order): Republic of Korea, Spain, Germany, United Kingdom of Great Britain and Northern Ireland, China, France and Japan. In brief, only 2.3 per cent of stimulus funding (accounting for 0.4 per cent of GDP) was green. Finally, it should also be noted that the European Union has committed to a stimulus package to build a green, digital and resilient Europe.[26]

26. Most of the green recovery spending has been committed to sustainable transport, such as electric vehicle transfers and subsidies, investments in public transport, cycling and walking infrastructure, followed by investments in low-carbon energy, which refers mainly to German and Spanish subsidies for renewable energy, hydrogen and infrastructure. A sizable amount of spending was also allocated to nature-based solutions, such as ecosystem regeneration, reforestation and public parks, notably in China and the United States of America, as well as energy-efficient building upgrades (mostly retrofits in France and the United Kingdom), and green research, development and demonstration for decarbonizing aviation, plastics, agriculture and carbon sequestration (see figure IV).

Figure IV
Green recovery spending in response to the coronavirus disease (COVID-19) pandemic in 2020



Source: Oxford University Economic Recovery Project, Global Recovery Observatory database, available at https://recovery.smithschool.ox.ac.uk/tracking/.

[26] See https://ec.europa.eu/info/strategy/recovery-plan-europe_en.

Impacts of current trends in digitalization and artificial intelligence

27. According to various measures, the COVID-19 pandemic has greatly accelerated digitalization among those who were already online at the beginning of 2020, making use of the Internet pervasive. As of January 2021, an estimated 4.8 billion of 7.8 billion people globally were Internet users. Of the 4.8 billion, 2.7 billion used Facebook. On a typical day in January 2020, 265 billion emails were sent, 794 million tweets were made, 7.5 billion YouTube videos were watched, 453 million video chats were made on Skype and 89 million videos were uploaded, producing an incredible 9.4 billion Gigabytes (GB) per day of Internet traffic. Also, on such a day, more than 4.3 million smart phones and almost 1 million computers were sold. In fact, in the first quarter of 2020 when businesses, schools and Governments in many parts of the world switched to telecommuting and video calls, traffic increased by around 40 per cent worldwide in barely more than a month. Reportedly, this massive move in response to the enduring crisis has greatly accelerated innovation in digital technologies and applications.

28. On the flipside, 3 billion people remain offline, unable to benefit from online education, employment or digital innovations. The pandemic greatly amplified existing technological and social divides – an issue that needs urgent addressing.

29. While the use of artificial intelligence dates back to before the 1950s, computing and data handling capacities reached a critical level in the 2010s with “deep neural networks” that can now surpass human cognitive capabilities in narrow, specific tasks, such as facial recognition and medical radiological diagnosis. Narrow artificial intelligence has become ubiquitous in many countries – unbeknownst to many. At the same time, billions remain excluded from being able to reap the benefits of artificial intelligence. Performance and capabilities grow at exponential rates, leading to new applications, new development models and sustainability concerns. Such developments have important implications for humanity’s aspirations, as expressed in the Sustainable Development Goals. However, future predictions are highly uncertain, which is particularly challenging, since the current artificial intelligence transformation appears to be proceeding about seven times faster than the industrial revolution of the past. Unless the issue is addressed, new socioeconomic divides will continue to arise from unequal ownership of artificial intelligence and other digital technologies.

30. The pandemic has resulted in the creation of an instantly expanded user base and market for many new services. Nonetheless, some underlying and pervasive technology trends have continued with surprising regularity. For example, the super-exponential growth in performance and energy use by large-scale providers, such as Google, Facebook and Amazon Web Services, since 2017 has continued unabated. The computing performance and energy efficiency of the top supercomputers continued to increase in 2020, precisely as it had been expected to do years ago. By November 2020, the Japanese Fugaku supercomputer had reached the current world record of 442 petaflops, which is roughly equivalent to 22 human brains – up from 201 petaflops just 11 months earlier. The top supercomputer is expected to reach the cognitive capacity of 10,000 human brains by 2030 and 700,000 brains by 2040. The total annual electricity consumption of the top supercomputers in each year rapidly increased from 12.6 GWh in 2006 to 88.4 GWh in 2019, even though the energy efficiency improved by a factor of 10 every five years. At the same time the number of supercomputers greatly increased. Hence, the emergence of supercomputers as a

significant contribution to world energy consumption which needs to be compensated by energy savings elsewhere.[27]

31. No official statistics exist for the computing power of all of the world's computers, smart phones and other devices – most of which are connected to the Internet. This collective global computing power was estimated to have reached 93 million petaflops in March 2021, the equivalent of 4.7 million human brains. By 2030, there might be an estimated 150,000 zettaflops or the equivalent of 7.7 billion human brains – basically a doubling in human cognitive capacity.

32. In his previous report, the Secretary-General pointed out that digital technologies and artificial intelligence in particular would require ever-increasing electricity and mineral resources, which would produce associated pollution and wastes (e.g., e-waste, nano-waste, and chemical wastes), in view of the fundamental limits to the increased energy efficiency of silicon-based computing. The situation arises mainly because additional applications that do not enhance efficiency will continue to increase energy demand, unless strict sufficiency considerations or limitations on energy use are introduced. Hence, the call for coherent technological and behavioural responses to this emerging challenge.

33. According to the previous report of the Secretary-General, indicative data for 2020 showed that digitalization and artificial intelligence were also on a "business-as-usual" trajectory. The Secretary-General stated that a wide range of new solutions would become available, albeit at the cost of rapidly increasing information and communications technology (ICT) energy use, with corresponding environmental consequences and widely unequal access to the new technologies. Artificial intelligence energy use increasingly started competing with other uses. In contrast, the "LED better futures" scenario would require strategic support of innovation aimed at rapidly increasing the efficiency of the energy and materials used in digital technologies and artificial intelligence. It would be necessary to make full use of such technologies in order to be able to design energy services that were highly efficient in all countries, thereby catalysing global sustainability.

IV. Digital consumer innovations and near-term actions for a sustainable development future

34. Fortunately, many promising digital consumer innovations already exist and can be deployed relatively quickly across the world. The examples below highlight the energy savings of such innovations and the potential reduction in greenhouse gas emissions. They indicate what would need to be done on the downstream, consumer-facing side – in addition to the many important upstream, supply-side actions – to embark on the "LED better futures" scenario.

Sustainable development benefits of digital consumer innovations

35. A range of disruptive digital consumer-facing innovations in buildings, mobility, food and in energy distribution and use is readily available for local adaptation and deployment across the world (see table 1). The innovations entail novel application of knowledge and can emerge in market niches and then improve exponentially, disrupting incumbent firms and markets, typically offering novel product or service attributes to consumers. Some of them appeal to low-end markets

[27] R. Roehrl, "Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system", TFM research paper No. 2, December 2019.

and price-conscious users, whereas others appeal to high-end markets and technophiles.

36. Potential savings resulting from such innovations in terms of reduced energy use and greenhouse gas emissions are very large, compared with what could still be achieved on the supply side. However, ranges of estimates are also very large, pointing to the importance of context, local adaptation and user behaviour (see table 1). For example, in some instances, digitally enabled home energy systems have led to energy savings of 91 per cent, while in some outliers they have even increased energy use by 9 per cent.

37. For digital consumer innovations in buildings, the highest average energy savings of around 77 per cent are expected from prefabricated whole-home retrofits, which are custom, high-efficiency building shells that are fabricated off-site. Smart lighting and appliances allow for customization and control, leading to savings of around 36 per cent. Heat pumps for heating and/or cooling extract heat from the air or ground. Home energy management systems integrate the management of heating, cooling, lighting, appliances and solar photovoltaic cells. Smart heating systems comprise automated monitoring and adaptive learning functions. Disaggregated feedback provides real-time energy data for households. Peer-to-peer exchanges of products and tools and for sharing spaces are facilitated through digital networks of individuals. It is important to note that energy savings of several of these innovations compound, so that overall energy savings are even larger. Recent studies have confirmed these enormous potential energy savings. For example, a study of the performance of 2000 "Passivhaus" dwellings found an average space heating energy consumption of 14.6 kWh per square metre per year – close to the intended design and a reduction of 88 per cent compared with the German average space heating demand – and that the vast majority of the variation in performance was due to user behaviour.[28] Consumer innovations in energy, which change how energy is supplied to, generated or managed by households (see table 2), have interrelated beneficial outcomes. For example, energy service companies that are third-party service providers managing energy use subject to performance contracts have typically led to anywhere from 10 to 50 per cent in energy savings in the United States.

38. Before the pandemic, telecommuting, namely, ICT-enabled remote work instead of commuting, had only led to a moderate 3 per cent savings in energy, due to compensatory behaviour, whereas virtual meetings between people in different locations have led to greater savings in energy (~84 per cent). Fully autonomous vehicles, electric vehicles and e-bikes could lead to very high savings and potentially drastic reductions in greenhouse gas emissions, but they could also increase energy use owing to changed behaviours.

[28] David Johnston and others, "Are the energy savings of the passive house standard reliable? A review of the as-built thermal and space heating performance of passive house dwellings from 1990 to 2018". *Energy Efficiency*, vol. 13, No. 81 (December 2020).

Table 1
Examples of disruptive digital consumer innovations in buildings, mobility/transport and food, in line with the "LED better futures" scenario

		Potential energy savings (percentage)	
Objective/type	*Innovation*	*Average*	*Range*
Interconnectivity for optimized use	Smart lighting	36	3 to 74
	Smart home appliances	..	wide range
	Disaggregated feedback	11	3 to 24
Improved thermal performance	Home energy management systems	23	-9 to 91
	Smart heating systems	17	-2 to 36
	Heat pumps	33	-16 to 70
	Prefabricated whole-home retrofits	77	70 to 84
Reduced demand for space and materials	Peer-to-peer exchange of goods	6	-1 to -12
Reduced demand for mobility	Telecommuting	3[a]	1 to 4[a]
	Virtual meetings and virtual reality	84	68 to 100
		60[a]	5 to 100[a]
Autonomous and clean/electric transport	Fully autonomous vehicles	3	-60 to +46
		42[a]	-4 to 93[a]
	Electric vehicles	56[a]	23 to 95[a]
	E-bikes	42[a]	-4 to 93[a]
Sharing economy	Car-sharing and car clubs	31	-4 to 65
	Peer-to-peer car-sharing	..	..
	Ride-sharing	13	1 to 33
	Shared ride-hailing/taxis	26	-7 to 61
	Neighbourhood electric vehicles	17[a]	4 to 39[a]
	Bike-sharing	12[a]	-100 to 12[a]
Interconnectivity for optimized use	Mobility-as-a-service	13	0 to 26
Reduce footprint of food sourcing	Digital hubs for local food	26[a]	-100 to 93[a]
	Meal kits/boxes	25	-100 to 86
		19[a]	4 to 23[a]
	Food-pairing applications	14	..
Reduce food waste	11th hour applications	21	18 to 24
	Food sharing	..	..
	Food gamification applications	13[a]	4 to 23[a]

Source: Adapted from Charlie Wilson and others, "Near-term actions for transforming energy-service efficiency to limit global warming to 1.5 °C", in *ECEE Summer Study Proceedings* (2019), based on a wide range of peer-reviewed academic articles.

Note: Specific examples of applications are listed in Charlie Wilson and others, "Potential climate benefits of digital consumer innovations", *Annual Review of Environment and Resources*, vol. 45 (2020).

[a] Carbon savings.

39. There are many new innovations available in the sharing economy with respect to mobility – all of which have significant energy or carbon benefits, without requiring a new infrastructure. For example, car-sharing (or car clubs) refers to a membership-based service offering short-term rental of vehicles. In peer-to-peer car-sharing, networks of car owners makes their vehicles available for short-term rentals.

Ride-sharing brings together passengers and drivers for shared car rides and commutes. Shared ride-hailing brings together multiple passengers in cars or minivans on similar routes booked on short notice. Bike-sharing is based on fleets of bicycles available for short-term rental. Neighbourhood electric vehicles are very lightweight, low-speed and battery-driven vehicles that are used on roads. Even a simple application-based scheduling, booking or payment system across modes ("mobility-as-a-service") can lead to a 13 per cent savings in energy.

40. Digital consumer innovations in the food sector lead to more moderate savings in energy use and reductions in greenhouse gas emissions, but they also have other benefits in terms of food, water, biodiversity and local livelihoods. For example, digital hubs for local food allow for food to be bought online directly from local producers. Meal kits or boxes provide home deliveries of fresh ingredients for cooking specific recipes. Food-pairing applications help to design vegetarian recipes using surplus ingredients. With eleventh hour applications, food outlets sell surplus fresh food at reduced prices. Food-sharing refers to the ICT-enabled sharing of surplus food of retailers or individuals with charities or individuals. Food gamification applications allow online gameplay to support reductions in food waste or meat consumption.

Table 2
Examples of disruptive digital consumer innovations in energy, in line with the "LED better futures" scenario

Objective/type	*Innovation*	*Explanation*
New service providers	Energy service companies	Third-party service providers managing energy use subject to performance contracts
	Energy aggregators	Municipal or market intermediaries enable consumers to group together for collective bargaining
	Third-party financing	Third-party service providers installing efficiency or renewables in homes on pay-as-you-save basis
Integrating consumers into grids	Demand response	Remote control of domestic appliances by utilities to reduce peak demand
	Time-of-use pricing	Tariff reflecting marginal cost of supply with high prices during peak periods
	Electric vehicle-to-grid	Allowing bidirectional flows between grid and batteries of electric vehicles when plugged in to charge
Decentralized energy supply	Peer-to-peer electricity trading	Networks of households for trading surplus electricity generated domestically
	Domestic electricity generation with storage	Electricity generated domestically stored in battery to maximize own consumption

Source: Adapted from Wilson et al. (2020).

41. Finally, it is important to note that these digital consumer innovations are driven by a cluster of enabling digital technologies that provide components of an essential infrastructure for digitalization, which requires urgent support for developing countries so that the innovations can be effectively used worldwide.

Cooperative, near-term actions for transforming service efficiencies

42. Universal access and a modern digitalization infrastructure will be indispensable to following a pathway like the "LED better futures" scenario towards attainment of the Sustainable Development Goals. Doing so could facilitate the deployment of digital consumer innovations like the ones highlighted above, as well as many others. Many of the innovations may be geared towards profitable business models, provided that the appropriate enabling environment and capacities have been built. Clearly, incorporating such innovations will take time and will require coherent, multi-stakeholder action, including by policymakers, regulators, mayors, service providers, innovators and consumers, in order to improve service efficiencies through a combination of technological, organizational and behavioural innovation. Table 3 provides an overview of 28 such near-term actions related to heating and cooling in buildings, ownership and use of consumer goods, and passenger mobility in cities.

43. A growing number of examples for these actions exist in developing and developed countries alike and could support mutual learning and scaling-up of cooperative, near-term actions for transforming service efficiencies. For example, in the top-runner programme of Japan, best-in-class products serve to define future product efficiency standards, which have to be exceeded by all manufacturers (averaged over their products) in five to eight years' time, followed by the next round of best-in-class products that are further improved. The programme applies to 30 product categories, from rice cookers to electric toilet seats. There has been an average of 40 per cent in energy efficiency improvements (ranging from 45 to 85 per cent) as a result. The "Energiesprong" initiative in the Netherlands is a government-funded innovation programme for net zero-energy home retrofits, focusing on social housing as an initial market niche. The "return and save" programme of Colombia grants a value added tax reduction for low- and medium-income households that exchange an old refrigerator or freezer for a new high-efficiency appliance (recycling rate of 75 per cent). The goal of the programme is to substitute at least 1 million refrigerators or freezers within five years.

Table 3
Proposed near-term actions in transforming service efficiencies consistent with the "LED better futures" scenario

	Who?	*Near-term action*
Consumer goods	Policymakers	Dynamic ratcheting up of product efficiency
		Incentives for high-efficiency, long-lived, reusable products
	Regulators	Open digital platforms for low-energy service providers
	Mayors	Space allocation for repositories of peer-exchanged appliances and tools
		Neighbourhood-scale testbeds for novel energy-service provision
	Service providers	Leasing or exchange of appliances linked to energy performance
	Innovators	Competitions and incentives for low-energy designs and business models
		Virtual aggregators for one-stop service provision requiring multiple skills or tools
	Consumers	Media consumption on low-energy mobile devices

	Who?	*Near-term action*
		Opinion leadership to challenge stigma of sharing and reuse
Urban mobility	Regulators	Enabling market access by new low-energy service providers
	Mayors	Point-of-use integration between multiple public and private modes
		Public procurement of electric vehicle fleets (including on-demand shared modes)
		Repurposing of road infrastructure for leisure, food, parks
	Innovators	Shared, responsive modes integrated into public transport networks
	Service providers	Co-location of electric vehicle charging points with local economic activities
	Consumers	Open real-time data on traffic flows and infrastructure usage
Heating and cooling	Policymakers	Demonstration and scale-up of "Passivhaus" energy performance
		Uptake of multi-functional devices (heat pumps, fuel cells)
		Consequential improvements to energy performance of rented or sold properties
	Regulators	Building code enforcement and compliance incentives
	Mayors	Legal tenure in informal settlements in exchange for improved building quality
	Mayors, innovators	Competitions to build locally adapted high-efficiency housing
	Service providers	Urban climate proofing to mitigate heat islands and weather extremes
		Area-based procurement of whole-home retrofits with potential for serialization
		Securitized third-party financing of urban scale retrofit portfolios
		Real-time energy monitoring in retrofit portfolios to reduce transaction costs

Source: Based on Wilson and others, "Near-term actions for transforming energy-service efficiency to limit global warming to 1.5 °C"

V. Issues for consideration

44. The following issues should be considered to support policymaking in the context of a successful decade of action. They complement the policy issues for consideration proposed in the report of the Secretary-General on the theme of the Council:

Response to the coronavirus disease (COVID-19) pandemic

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

(b) Reorient financial stimulus packages to address a recovery that is green and sustainable, and that is focused on research and development and technology;

(c) Urgently address the persistent technology divides that have excluded billions of people from reaping the benefits of digital innovations;

Digital consumer innovations and end-use efficiencies

(d) Facilitate and prioritize investments in and coordinated actions on technology efficiency, business innovation and behavioural change to rapidly increase end-use efficiencies in energy, water and land use, as inspired by the "LED better futures" scenario;

Digital consumer innovations

(e) Unlock the large untapped potential of digital consumer innovations in mobility, food, buildings and energy services, which could be readily deployed worldwide (see table 1);

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

(g) Consider action on the cooperative, near-term actions proposed in table 3 for transforming service efficiencies, commensurate with the Goals and climate aspirations;

Stakeholder cooperation

(h) Strengthen international cooperation on science and technology solutions for the Goals;

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

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

United Nations system

(k) 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;

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

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