United Nations E/HLS/2020/5

Economic and Social Council

Distr.: General
07 May 2020
WORD COUNT: 7,062

Original: English

ADVANCED UNEDITED VERSION

High-level Segment of ECOSOC
Economic and Social Council
17 July 2020
Item 5 of the provisional agenda*

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

The present report serves to inform the ECOSOC high-level segment in July 2020, complementing report E/HLS/2020/.. on the theme. Current decisions taken in the context of the COVID-19 pandemic as well as on new Internet applications and artificial intelligence may have long-run implications on humanity's capacity to deal with great global challenges in the future. Building on these trends, the report examines a global transformative best-case scenario pathway to achieve the SDGs and sustainable development until 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 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. Its aim is to enhance knowledge-sharing and regional and international cooperation*". The present report serves to inform the ECOSOC 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*" to convene on 17 July 2020. The report complements and builds on the Secretary General's report (E/HLS/2020/..) on the ECOSOC theme of "*accelerated action and transformative pathways: Realizing the decade of action and delivery for sustainable development*".

2. This report presents a set of best-case, aspirational long-term scenarios in line with the SDGs and contrasts them with business-as-usual and worst-case scenario outcomes for 2030 and 2050. It also explores the consequences of the COVID-19 pandemic as well as new Internet technologies and artificial intelligence. Current and near-term decisions in these two areas are expected to strongly influence our capacity and available options to deal with other great sustainability challenges that humanity is facing in the longer run.

3. The 2030 Agenda for Sustainable Development outlines a broad, aspirational vision "*for people, planet and prosperity*".[1] Its SDGs and targets provide a quantitative and qualitative snapshot of what the world would like to have achieved by 2030.[2] It also outlines policy recommendations and actions, but it does not offer a precise guidance on how coordinated actions could feasibly unfold over time to reach the SDGs. This is what scenarios are designed to explore. Scenarios are internally consistent and plausible paths describing developments into the future. They coherently bring together scientific and technical knowledge from all relevant disciplines and sources, in order to improve our understanding of possible future developments and support decision-making and planning about the future. Policy makers often refer to scenarios as pathways – a terminology that is used synonymously in this report.

4. However, scenarios "*are neither predictions nor forecasts*".[3] The future is uncertain, and thus scenario analysts need to make assumptions about the future, about underlying system dynamics and scenario drivers, uncertain scientific relationships, about 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. Hence, scenario analysis is sometimes said to be more art than science. However, it focuses our thinking on identifying and testing feasible solutions to our world's main challenges in the future – solutions that do not breach physical, technical, economic or socio-political boundaries, but that truly "*add up*" and that are grounded in the best science and evidence available.

6. The scenario presented by this report is a "*best-case scenario*", also referred to as "Low energy demand (LED) scenario" or "*better futures scenario*".[5] It is a consistent and highly aspirational scenario inspired by the latest technological

[1] A/RES/70/1 - Transforming our world: the 2030 Agenda for Sustainable Development
[2] With selective targets for other years
[3] IPCC (2000). Special Report on Emission Scenarios (SRES).

developments, behavioural change and high impact business innovations. The scenario explores what is needed now and in coming years, in order to achieve the SDGs by 2030 and to further sustainable development until 2050. Several scenario variants are highlighted to indicate the potential for alternative routes and decisions. The best-case is compared to a "*business-as-usual scenario*" which is grounded in continuing present trends and current policies into the future, as well as to a "*worst-case scenario*" that highlights key risks and important decision-branching-points. The substantive scope of the scenarios follows that of the SDGs, but leaves out a number of institutional, governance and social issues that are hard to quantify which however, remain part of the overall storyline. The scenarios were developed by some of the world's leading scenario modelers[4]. Table 1 provides an overview of the scenarios.

Table 1. Scenario overview

		Scenario 1: **Best-case scenario**	**Scenario 2:** **Business-as-usual (BAU) scenario**	**Scenario 3:** **Worst-case scenario**
Scenarios	**described here**	"Low-energy demand" (LED) & "Better Futures"	SSP2-4.5 scenario with current/stated policies; FOLU's current trends scenario	SSP5 RCP 8.5 and SSP3 scenarios
	related variants	PBL's Nexus, 1.5°C and roads from Rio scenarios; IEA's World Energy Outlook sustainable development scenario	IEA's World Energy Outlook stated policies scenario	
Scenario rationale		Extremely high end-use efficiencies and behavioral and business innovations in energy, water and land use drive rapid transition fueled by new ICT.	Continuation of current trends, practices and technology change, and implementation of stated policies (e,g., GHG measures as per the NDCs).	Fragmented world unable to deal with its larger global challenges.
Assumptions		Interconnected, science & technology and education focused world; global diffusion of technology; open science; common ambition to achieve sustainable development.	Continuation of today's governance systems; continuation of rapid technological progress amid great socio-economic and technological divides.	Fragmentation and collapse of the multilateral system. Barriers to access to knowledge and technologies.
COVID-19 aspects		Reinforced global cooperation; S&T engagement; quick pandemic end and recovery	Mainly national responses and lingering effects until 2021.	Major protracted health disaster and economic depression.
AI aspects		Many high efficiency applications balanced with sufficiency considerations.	Many useful applications but increasing AI energy demand and environmental impacts. AI energy use competing with other uses.	Fewer AI solutions emerge and quickly hit energy limits. AI highly concentrated in few countries. No significant efficiency improvements in energy and materials.
Results	**in 2030**	SDGs achieved.	Progress towards the SDGs, but major gaps remain.	Progress in few areas but also regress in others.
	in 2050	Sustainability of a high-tech interconnected world.	Significant.	Major sustainable development disasters

[4] 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, IPCC and IPBES reports, the International Resource Panel, and The World in 2050 (TWI2050) Initiative.

Sources: Gruebler et al. (2018)[5], Riahi et al. (2017)[38], FOLU (2019)[21], Van Vuuren et al. (2105, 2018 and 2019)[34,32,33], IEA (2019)[6]. Their data are available from the Low Energy Demand (LED) scenario database[7] and the Shared Socioeconomic Pathways (SSP) databases[8], from IIASA, PBL and IEA. WEO =World Energy Outlook.

II. Current trends and scenario "wild cards"

7. There are a number of current, pervasive, and long-run trends that strongly shape possible futures. These so-called "*scenario drivers*" include, inter alia, population and demographic trends; increasing prosperity, health and quality of life; rapid urbanization in the developing world (particularly in mid-size cities); novel infrastructure services; decentralization allowing new end-user roles (from consumer to producer, innovator and trader); and ICT innovation. Along similar lines, the report of the Secretary General on theme of the ECOSOC entitled "*Accelerated action and transformative pathways: realizing the decade of action and delivery for sustainable development*" details selected trends and elements of transformative pathways in some of the entry points for action as proposed by the GSDR 2019.[9] These are all extremely important elements for understanding long-run SDG scenarios. However, there are two areas in which decisions taken in the short-term will likely have decisive consequences on the feasibility of long-run future pathways: the COVID-19 pandemic as well as new Internet applications and artificial intelligence.

The COVID-19 pandemic

8. On 11 March 2020, the WHO declared the COVID-19 pandemic. As of the time of writing (22 April 2020), events rapidly unfolded and the pandemic had impacted every country on the planet. More than 2.6 million people had tested positive for the virus, at least 180,000 people had died and 720,000 recovered. Due to insufficient testing and reporting, the true numbers of infections and deaths were likely much larger – infections worldwide are likely one to two orders of magnitude higher according to statistical estimates. This would mean that anywhere between 20 to 200 million were already likely infected at the time. According to epidemiological model results, millions might die in the coming months - anywhere between 1.9 and 40 million fatalities until the end of the pandemic, depending on policy measures taken (Figure 1). This might include several waves of infection until either wide-scale vaccinations or herd immunity are achieved.[10]

9. About 2.6 billion – or one-third of the human population – were in lock-down at the beginning of April and more than hundred countries had closed their borders, with severe economic impacts. Tens of millions of jobs have already been lost and the

---

[5] Gruebler, A., Wilson, C., Bento, N. et al. (2018). A low energy demand scenario for meeting the 1.5°C target and sustainable development goals without negative emission technologies. Nat Energy 3, 515–527 (2018). [including extensive supplementary information] https://doi.org/10.1038/s41560-018-0172-6

[6] IEA (2019). World Energy Model - scenario analysis of future energy trends. World Energy Outlook, Nov. 2019 https://www.iea.org/reports/world-energy-model

[7] LED database hosted by IIASA at https://db1.ene.iiasa.ac.at/LEDDB presenting data published in Gruebler et al. (2018).

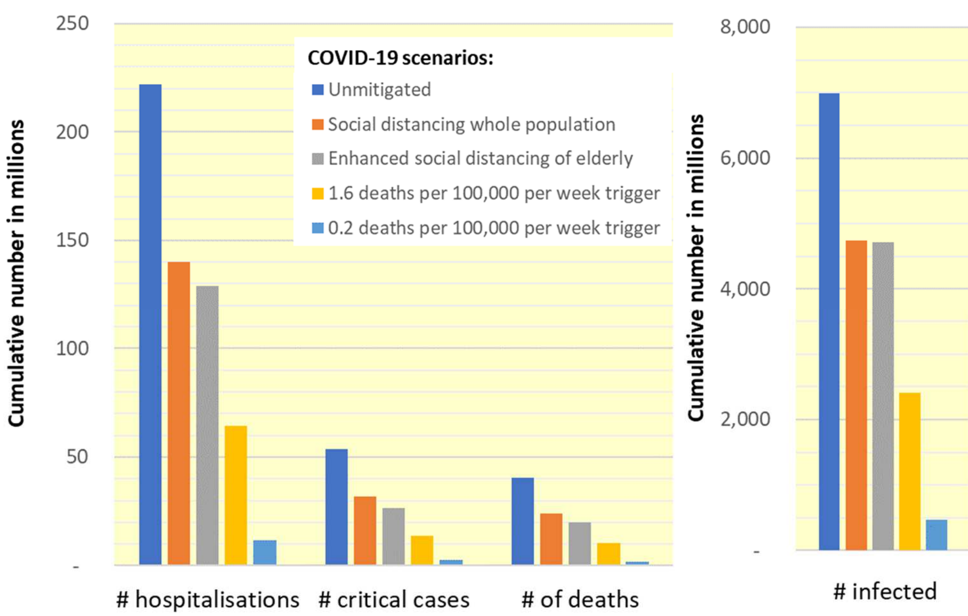
[8] SSP database hosted by IIASA at https://tntcat.iiasa.ac.at/SspDb presenting data published in Riahi et al. (2017)

[9] 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).

[10] Patrick GT Walker, Charles Whittaker, Oliver Watson et al. The Global Impact of COVID-19 and Strategies for Mitigation and Suppression. Imperial College London (2020), doi: https://doi.org/10.25561/77735

world economy was expected to enter a deep recession (see DESA policy briefs series, SG report E/HLS/2020/xx on the theme). Science and technology capabilities leave no doubt that humanity will ultimately defeat the novel coronavirus. However, it remains unclear how both the pandemic itself and its socio-economic impacts will play out in the coming months, to which extent the unprecedented, socio-economic and policy measures taken in the midst of this crisis will predetermine the world's long-run future pathways and will potentially constrain our capacity to deal with future sustainability risks. Indeed, our response to the pandemic appears to play a wild card role. We are at a branching point where humanity will either opt for closer international collaboration or for a weakening of the current system of international cooperation. The following short-term COVID-19 choices lead to the three long-term scenarios described further below.

Figure 1: Global, cumulative number of infections, hospitalizations critical cases and fatalities until the end of the COVID-19 pandemic



Source: DESA, illustrating estimates reported in Walker et al. (2020)[10], *Note:* Results in terms of cumulative numbers of hospitalisations, critical cases requiring ICU treatment, and fatalities until the end of the pandemic, for five epidemiological scenarios that explore increasingly stringent social distancing policy measures. (1) Unmitigated: a scenario in which no action is taken; (2) Social distancing whole population: measures to uniformally reduce the rate at which individuals contact one another (by around 45%), short of complete suppression; (3) Enhanced social distancing of the elderly: as scenario (2) but with individuals aged 70 years or more reducing their social contact rates by 60%; (4) and (5) Suppression: assuming that wide-scale intensive social distancing (modelled as a 75% reduction in interpersonal contact rates) are taken with the aim to rapidly suppress transmission and minimize near-term cases and deaths, whenever 1.6 deaths or 0.2 deaths per 100,000 people per week are reached, respectively. [11]

[11] Considerable scientific uncertainty remains about the contagiousness of the virus, measured as R0 for which the best guess estimate of 3 was used in the calculations, i.e., without policy interventions each infected individual further infects three individuals. Estimates for R0 range from 2.4 to 3.3, which gives a fatalities range for scenario (1) of 35 to 42 million, for scenario (2) of 20 to 26 million, and for scenario (3) of 12 to 22 million.

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

11. COVID-19 scenario 2 (business-as-usual): In this scenario, there will be continued global cooperation through the existing institutions, but in times of crisis the focus is on the national responses, most of which remain uncoordinated with each other. Policymaking continues to consider scientific evidence and technological possibilities, but these vary greatly across governments and societies, and often remain limited. Other collaborations across science and technology communities have grown in response, holding promise for enhanced cooperation in the future, but many of them will remain under-resourced and small-scale. Various COVID-19 vaccines will be available by the first or second half of 2021. A global vaccination programme might ultimately defeat the virus in 2021, opening the way to economic recovery. However, various transport restrictions will be enduring, and businesses and governments will have 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.

12. COVID-19 scenario 3 (worst case): In this scenario, the current crisis will lead to a perception of the multilateral system as increasingly irrelevant, with responses happening at the national level in uncoordinated fashion and with governments competing over health equipment and economic resources. Vaccines will become available by 2021 in a number of countries but might not be accessible to many. Transport and travel restrictions will only slowly be lifted – with some becoming enduring. In absence of effective globally coordinated economic recovery actions, a global economic depression is likely, leading to a world lacking the capacity and willingness to jointly address the great global challenges facing humanity in the future.

New technologies, Internet applications and artificial intelligence

13. The fast pace of technological change in recent years in robotics, artificial intelligence (AI), biotechnology, nanotechnology and related areas such as "big data" are having broad impacts on economy, society and environment. At the heart of these trends are telecommunications ICTs. On the one hand, these emerging technologies hold great promise for a range of high-efficiency energy and water systems that could be deployed in all countries catalyzing global sustainability. On the other hand, despite efficiency increases, these technologies and especially AI will require ever-increasing electricity and mineral resources with its associated pollution and wastes (e.g., e-waste, nano-waste, and chemical wastes), 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 non-efficiency enhancing applications will continue increasing energy demand, unless strict sufficiency considerations or energy use limits are introduced.

14. The best guess estimate of the entire global Internet's energy used is about 2,000 TWh or 7.2 EJ for 2019, which is equivalent to about 9 per cent of total global electricity use. Roughly half of the total, or 966TWh, was due to consumer devices,

such as computers, mobile phones, laptops and TVs. The remainder (1,022 TWh) was due to local, fixed and mobile networks, data centers, and the manufacturing of the various components. Excluding consumer devices, the remainder alone caused emissions of about 949 $MtCO_2$ in 2019. The mobile networks component, in particular, is expected to rapidly increase with the advent of 5G and mobile video streaming services. Video streaming alone accounts for annual carbon emissions equivalent to that of Spain.[12] The short product life cycle of electronic products such as smartphones and computers is responsible for the large amount of electronic and electrical waste that the world produces every year. The energy production footprint of all smartphones in the world was about 30 per cent larger than that of all passenger cars.[13] Currently, as much as 50 million tonnes of e-waste is produced annually, which weigh more than all the commercial aircrafts ever built - only 20 per cent of them is formally recycled.

15. Moore's law (coined in 1965) stated that the number of transistors in a dense integrated circuit would double about every two years – a relationship that held for 50 years, driving exponential performance improvements of electronics. Dennard scaling (coined in 1974) said that as transistors get smaller their power density would stay constant, so that the power use stays in proportion with area. This allowed CPU manufacturers to raise 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 automatically getting faster nor more energy efficient.[14] Due to ingenious design, supercomputers on the other hand have continued to increase their performance along an exponential path. By 2014, the top supercomputer for the first time surpassed 20 Petaflops - roughly the hardware-equivalent of the human brain[15]. It reached a peak performance of 201 Petaflops (~10 brains) by the end of 2019, and might correspond to 500 brains by 2025, 10,000 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 5 years. Hence, the rapid emergence of supercomputers as significant contribution to world energy consumption. [16]

16. Deep-learning neural networks (DNN) – the most successful current artificial intelligence (AI) technology - are highly data- and computing-intensive technology. A state-of-the-art DNN model for facial recognition in 2019 required an estimated 656 MWh for the training phase, leading to 313 tonnes of CO_2 emissions. [17]

17. Hence, new Internet applications and artificial intelligence are another area in which current decisions may have an outsized influence on future long-term possibilities.. 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 behavioral change towards sufficiency. However, recent trends call in question under which circumstances such balance can

[12] Efoui-Hess, M. (2019). Climate Crisis: The unsustainable use of online video - the practical case for digital sobriety. The Shift Project

[13] Smil, V.

[14] Sze, V., (2019). Efficient Computing for AI and Robotics. MIT lecture. May 2019.

[15] According to Flow Genome Project founder Steven Kotler. See: Diamandis, P.H. and Kotler, S., (2015). Bold: How to Go Big, Create Wealth and Impact the World, Simon & Schuster, ISBN-10: 1476709564.

[16] Roehrl, R. (2019). Exploring the impacts of ICT, new Internet applications and artificial intelligence on the global energy system. TFM research paper, December 2019, https://sustainabledevelopment.un.org/index.php?page=view&type=12&nr=3335

[17] Strubell, E., Ganesh, A., McCallum, A., (2019). Energy and Policy Considerations for Deep Learning in NLP. arXiv:1906.02243v1 [cs.CL] 5 Jun 2019.

be achieved in the longer run. The energy demand of Internet applications and artificial intelligence and associated GHG emissions – while relatively small in the past – have already become significant and continue to increase unabated. These technologies are key to "smart" energy systems and to further increasing the overall energy efficiency. However, new technologies will also continue leading to entirely new services, most of which are not geared toward increasing the efficiency – hence further increasing global energy demand. The energy efficiency of ICTs has reached fundamental limits, while overall computing performance and usage increases unabated. The energy efficiency of current silicon-based computing is at least an estimated four to five orders of magnitude lower than human brains. The most likely result of these trends will be accelerated, increased energy demand for the Internet and AI, unless sufficiency considerations fundamentally change the current direction.

18. The overall effect of Internet and AI technologies on global energy and materials in the coming years remains highly uncertain and will depend on technology choices, standards, efficiency and sufficiency policy choices. Not surprisingly, best guess estimates for overall ICT energy use in 2030 show an extremely wide range from 2,067 to 8,265 TWh.[18] This uncertainty is also reflected in a recent expert survey which showed that a majority of experts and scenario analysts expected an increase of global energy demand over and above the dynamics-as-usual trends until 2030. A minority of experts (20%) expected a decrease and almost one third (30%) of respondents highlighted uncertainty factors.[16]

19. AI scenario 1 (best-case): In the best case, the full range of new technologies and AI will be available to increase overall energy and materials efficiency and to design new solutions to many of our challenges, at a cost of only moderately increased energy consumption, provided disruptive innovations achieve continued rapidly increased AI and computing energy efficiencies, despite the break-down of Moore's law.

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

21. AI Scenario 3 (worst case): In this scenario, fewer AI solutions emerge and quickly hit their energy limits. AI is highly concentrated in only few countries. As a result, only few countries benefit significantly from AI, and there is no dramatic change in global energy and materials efficiencies.

III. Long-term scenarios towards the SDGs and beyond

22. Ever since the Rio+20 Conference in 2012, many scenario modelers have developed global sustainable development scenarios and since 2015 also more specifically SDG scenarios. They emphasize economic, technological, or political approaches. However, in the past eight years, unabated global increases in energy, materials and land use, together with their associated environmental, social and health consequences, have required analysts to make ever more ambitious scenario assumptions to achieve the SDGs in the remaining fewer and fewer years.

23. To take for example SDG13 (climate change goal), GHG emissions would need to be reduced by 7.6% per year until 2030, compared to a reduction of only 3.3% per year, had decisive action been already taken ten years ago.[19] To achieve such

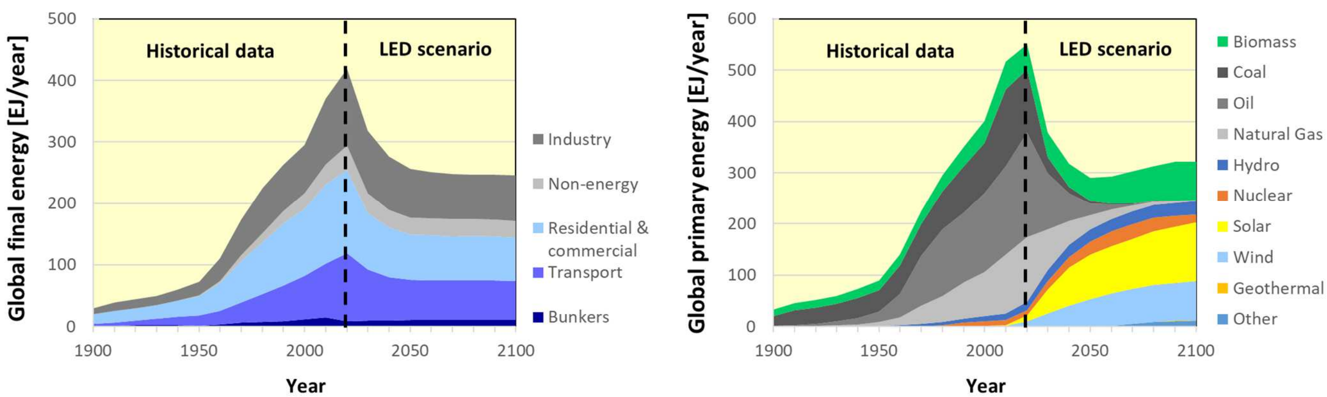
[18] Andrae, A., (2019). Drawing the fresco of electricity use of information technology in 2030 – Part II. Preprint Feb. 2019. Doi:10.13140/RG.2.2.31813.91361.
[19] UNEP gap report 2019.

ambition, many scenario analysts have assumed yet unproven technological fixes, such as bioenergy with carbon capture and storage (BECCS), to produce negative emissions at a large scale, especially 30 years from now. Not only are there issues with the logistics of safely storing billions tonnes of CO_2 every year, but also with large-scale land-use for bio-crops.

The best-case scenario: "LED Better Futures"

24. Against this background, in 2018 several eminent scenario analysts and scientists took a different approach and designed a scenario that aims to make exceptional progress on Sustainable Consumption and Production (SDG12) through rapid transitions to lower primary use and high efficiency end-use technology and practices in energy, water, land and materials. To an original global low energy demand or LED scenario[20], consistent, detailed scenario implementations were developed for land use and food ("better futures" scenario)[21], water[22] and other SDG sectors. The resulting "LED Better Futures" scenario translates into important benefits for all SDGs.

Figure 2. Global primary and final energy demands in the LED scenario



Source: Gruebler et al. (2018)[5]. *Historical data:* PFUDB (De Stercke, 2014)[23]

25. The LED scenario meets the 1.5°C climate target and the SDGs without relying on negative emission technologies, such as bioenergy with carbon capture and storage (BECCS), and thereby sparing hundreds of millions of cropland. Most importantly, by 2050 it reaches a global final energy demand of only 245 EJ[24], which is 40% lower than today, despite rises in population, incomes and activity. In fact, it is known as the lowest long-run final energy demand scenario in the literature. However, this does not come at the expense of energy services which continue to increase to levels assuring "decent standards of living" for all – on a global level well above access and

[20] Gruebler A , Wilson C , Bento N, Boza-Kiss B, Krey V , McCollum D, Rao N , Riahi K , et al. (2018). A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies. Nature Energy 3 (6): 517-525. DOI:10.1038/s41560-018-0172-6.

[21] FOLU (2019). Growing Better: Ten Critical Transitions to Transform Food and Land Use. The Global Consultation Report
of the Food and Land Use Coalition, September 2019.

[22] Parkinson S, et al. (2018). Balancing clean water-climate change mitigation tradeoffs. IIASA Working Paper. IIASA, Laxenburg, Austria: WP-18-005

[23] De Stercke S (2014). Dynamics of Energy Systems: A Useful Perspective. IIASA Interim Report. IIASA, Laxenburg, Austria: IR-14-013, https://pure.iiasa.ac.at/id/eprint/11254/ , with database: https://tntcat.iiasa.ac.at/PFUDB/dsd?Action=htmlpage&page=welcome

[24] excluding an additional 10.5EJ in international bunkers (used by international maritime and air transport).

poverty thresholds and well above many other scenarios, through radical improvements in efficiencies. In other words, end-use devices and service provision become vastly more efficient over the next ten years. The result is “peak energy” by 2020 and rapid electrification (Figure 2). Current rates of renewable energy deployment would suffice to meet future energy needs. The end-use transformations drive upstream decarbonization, as the much smaller size of the global energy system makes it significantly easier to achieve a low-carbon supply-side transformation. Table 2 provides an overview of key scenario parameters.

In the LED scenario, almost half the energy demand reduction until 2050 is due to technology adoption decisions[25], the other half due to behavioural change[26]. Between 2019 and 2030, annual global investments of about US$45 billion (twice those in the BAU scenario) are needed to achieve universal energy access (SDG&), most of it for electricity access. This amounts to less than 2% of the total annual energy sector investment. In the LED scenario, overall energy supply investment requirements for fuel systems, power plants and networks increase only slightly until 2030 and decrease thereafter. This is because in the coming decade the required increases in power supply investments are about as large as the expected reductions in fuel systems investments. However, investments in energy end-use (e.g., appliances) and services, as well as related business opportunities will rapidly expand. While the publication of the LED scenario does not provide comprehensive investment numbers for end-use and services, the IEA’s WEO sustainable development scenario which has similar end-use focus provides further insight[27]: for the 2019-2050 period compared to the 2014-2018 period, annual investments are expected to increase from $1.71 to $1.92 for fuel and power systems, and from $0.37 to $1.64 trillion for energy end-use, resulting in total investments increasing from $2.08 to $3.56 trillion per year. However, much of the end-use efficiency investments would ultimately benefit consumers through lower electricity and fuel costs.

Table 2. Comparison of the LED Better Futures scenario with the Business-as-usual scenario

	Today	LED scenario		Business-as-usual (SSP2-4.5)		
	2020	2030	2050	2030	2050	
Population	7.6	8.3	9.2	8.3	9.2	billion
GDP (PPP)	101	143	231	143	231	trillion US$2010/yr
GDP (mer)	71	109	197	n.a.	n.a.	trillion US$2010/yr
Energy supply investment	1.17	1.25	1.05	n.a.	n.a.	trillion US$2010/yr
Final Energy	410	309	245	509	618	EJ/yr
Primary Energy	551	378	289	645	771	EJ/yr
Agricultural Production	4.1	4.7	5.9	5.4	6.9	billion t DM/yr
Food Demand	2,905	2,985	3,130	n.a.	n.a.	kcal/cap/day
CO2 emissions	39.6	16.2	2.7	43.5	43.5	Gt CO2/yr
Radiative forcing	2.7	2.9	2.7	3.0	3.7	W/m2
Water consumption	2.4	2.4	2.3	n.a.	n.a.	1000 km3/yr

Data sources: LED scenario and SSP databases[7,8] [28]

26. The LED scenario explores new social, behavioural and technological innovations. This includes high performing innovations at the fringes of current markets. The scenario shows what could feasibly be achieved in terms of energy efficiency (a two to four-fold reduction) in buildings, transport, and consumer goods manufacturing.[29]

[25] e.g., high efficiency vehicles, appliances
[26] e.g., shared mobility, public transport, building insulation
[27] https://www.iea.org/reports/world-energy-model/sustainable-development-scenario#abstract
[28] Primary energy is calculated using the physical energy content approach.
[29] UN (2011). Chapter 2 of the World Economic and Social Survey 2011.

Table 3. Transformations of end-use services and upstream sectors in the LED scenario (2020-2050)

		Activity levels	***Energy intensity***
End-use services	Thermal comfort	Roughly constant in Global North and 35% increase in Global South converging on a global average of 30m^2/capita.	High service-efficiency thermal end-use technologies combined with doubling of retrofit rate (Global North) and new build standards (Global South) reduces energy intensity by 75% in Global North to around 160-170 MJ/m^2 and by 86% in Global South to 40 MJ/m^2.
	Consumer goods	Doubling in Global North to 42 devices per capita; tripling in Global South to 24 devices per capita.	Fall in global average electricity intensity, weighted by share of total devices, from 93 to 82 kWh/device, with strongest reductions in lighting and appliances.
	Mobility	Doubling across all modes (particularly flexible route shared vehicles) in the Global South; 20% fall in the Global North with larger reductions in road-based modes offsetting increases in rail and air.	70% fall in global average energy intensity weighted by modal share, with strongest reductions in road-based modes, resulting from electrification, shared fleets, flexible public transit, and active modes.
	Food	Increase of food demand by 70-100% globally, combined with the continuation of dietary transition. Food availability is solved in Global South, reaching appropriate calorie intake.	n.a.
Intermediate and upstream sectors	Commercial & public buildings	43% increase to 23m^2/capita in Global North and 50% increase to 9m^2/capita in Global South.	Falls 76% to an average of 139 MJ/m^2 in Global North and falls 90% to an average of 44 MJ/m^2 in Global South.
	Industry	Demand for global commodities (steel, aluminium, cement, paper, petrochemicals, and feedstocks) falls by around 15% to 6.4 Gt as a result of dematerialisation (1/3) and improvements in material efficiency (2/3).	Global average energy intensity, weighted by activity shares of specific manufacturing and construction processes, falls by a fifth to 16.7 GJ/t.
	Freight transport	Rises by around 20% in the Global North to 64 trillion t-km, and by around 70% in the Global South to 58 trillion t-km, with stronger increases in rail (and shipping) and some reduction in truck activity.	Global average intensity (MJ/t-km) falls by 50% to 0.5 - 0.7 MJ/t-km for trucks and by 10% to 0.2 MJ/t-km for rail. Limited potentials for electrification in shipping and aviation, so no significant intensity changes.

Source: Gruebler et al. (2018)[5]

27. ICT in general and AI in particular will have applications and impacts in 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 in the scenario. Table 3 provides a quantitative summary of the major transformations of end-use services and upstream sectors. The achieved energy demand reductions in all sectors are so large they would likely pale in comparison to associated increases in AI energy demand. 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% by 2050. This is much more than the 3% power increase due to computing in a typical self-driving passenger car prototype.[30] 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% by 2050. AI can 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 AI chips and robotics that continue to significantly increase their energy efficiency, despite Moore's law breakdown. The scenario developers detail energy and emissions reduction potentials for 99 innovations, in energy, mobility, food, buildings & cities.[31]

28. Renewed efforts in R&D, technology diffusion, and infrastructure investments support higher yields, increasing resource productivity. Combined with regenerative farming practices; reduced food loss and waste; dietary shifts towards less resource-intensive proteins; and protection of and payment for the ecosystems services provided by forests, oceans and soils, food systems, will greatly benefit the environment, biodiversity, oceans, local livelihoods and rural poverty reduction. Enough food will be produced in 2030 to deliver on SDG2 to end hunger, achieve food security and improved nutrition and promote sustainable agriculture. The LED better futures scenario fares vastly better than BAU (Table 4).

Table 4. Land, food, biodiversity and oceans in the LED Better Futures vs. the Business as usual scenario

	LED 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	-1200	200	400	million ha (vs. 2010)
Restored natural land	450	1300	100	225	million ha (vs. 2010)
Food insecure people	0	n.a.	475	n.a.	million
Biodiversity Intactness Index	-0.6%	0.2%	-1.8%	-3.2%	vs. 2010
Death due to high BMI	4.0	5.6	6.4	10.1	million people/year
Food and landuse emissions	4.7	0	12	13	$GtCO_2e$/year
Oceans - mariculture of bivalves	n.a.	80	n.a.	3	million metric tonnes
Oceans - wild catch	n.a.	24%	n.a.	-15%	increase vs. 2010

Data source: FOLU (2019)[21]

29. Higher aggregate agricultural productivity (+1.1% per year), reduced food loss and waste (-25% by 2050) and dietary shifts (with oceans delivering 40% more proteins until 2050) allow shifting more than 1.5 billion hectares of land away from agriculture, compared to the BAU scenario. In the coming decade, negligible conversion of forests and other natural ecosystems is in principle possible, but immediate action will be needed before 2025. The additional social benefit of GHG emissions reductions in the scenario is estimated at an enormous US$1.3 trillion per year, mainly related to protection and restoring of tropical forests. Biodiversity declines are reversed already in the 2020s. As demand and production methods change in the coming years, the advantages of high intensity agriculture are eroded, reducing overuse of fertilizers and herbicides/pesticides. Healthier diets could reduce the number of people dying prematurely due to diet-related overweight and obesity, from over ten million to less than 6 million by 2050.

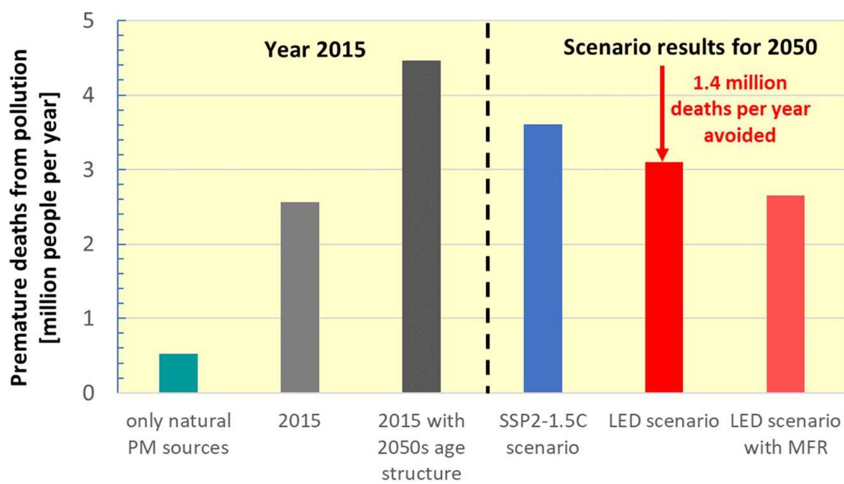
[30] Self-driving car prototypes typically used 2.5kW of computing power, compared to 75kW of a typical car with 100HP engine. Cameras and radar alone generated about 12 GBytes of data per minute, with some prototypes requiring water cooling (Source: Wired Magazine, Feb. 2018).

[31] Wilson, C., Pettifor, H., Cassar, E., Kerr, L., Wilson., M., (2018). The potential contribution of disruptive low-carbon innovations to 1.5°C climate mitigation, Energy Efficiency, https://doi.org/10.1007/s12053-018-9679-8.

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 US$11.9 trillion in 2018, which was $1.9 trillion larger than the entire market value of the global food system of $10 trillion. The "better futures scenario" would reduce these costs to $5.5 trillion in 2050, compared to an increase to $16.1 trillion in the business-as-usual scenario.[21] In fact, increased investment of 0.3% of global GDP, or $350 billion per year in human capital, technologies and the food and land system 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 to current trends and create an additional 120 million more decent jobs.

31. Reduced ambient air pollution (PM2.5) could avoid 1.4 million premature deaths per year by 2050 compared a continuation of current practices, and about 1 million per year compared to a SSP2 scenario variant that achieves the same 1.5°C climate target but otherwise follows our business-as-usual assumptions(Figure 3). Such major reduction is expected to benefit especially the poor who are most exposed.

Figure 3. Premature deaths from ambient air pollution (PM2.5) in 2015 and in selected scenarios by 2050



Source: Gruebler et al (2018)[5]. *Note:* MFR= maximum feasible emissions reductions with near-term technology. SSP2-1.5C is the Business-as-usual scenario, but with 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 to reach the SDGs should one or the other of the ambitious assumptions not be realized. For example, PBL researchers and others proposed a 1.5°C scenario towards the SDGs that is similar to LED with rapid electrification in the end-use sector, but it does include some BECCS and bends the curve towards sustainability more through lifestyle changes than technology.[32] Their latest Nexus Scenario is fully integrated and explores diet-change, agriculture efficiency, climate policy, biodiversity and water and illustrates the much reduced energy and resources system.[33] And their "Roads from Rio"-scenario dates back to the Rio+20 Conference but includes detailed quantifications of many of goals that later became SDGs.[34]

[32] van Vuuren, D.P., et al.(2018). Alternative pathways to the 1.5°C target reduce the need for negative emission technologies. Nature Climate Change, Vol. 8, May 2018, p. 391–397. https://doi.org/10.1038/s41558-018-0119-8

[33] van Vuuren, D.P., et al. (2019). Integrated scenarios to support analysis of the food–energy–water Nexus. Nature Sustainability, Vol.2, Dec. 2019, p. 1132–-1141.

[34] van Vuuren, D.P., et al. (2015). Pathways to achieve a set of ambitious global sustainability

Another scenario explores the maximum global cropland-sparing potential of high-yield farming. It concludes cropland requirement can be reduced by almost 40%, even if 20% of cropland is released for landscape elements and cropland in biodiversity hotspots is spared.[35]

Comparison with business-as-usual scenario

33. Many elements of the business-as-usual (BAU) scenario were already presented in comparison to the LED better futures scenario above. It sees significant progress towards the SDGs, but major gaps will remain in 2030. BAU is based on assuming a continuation of current trends, practices and technology change, and implementation of stated policies.

34. For the energy sector, BAU is similar to IEA's stated policy scenario in its World Energy Outlook. As a typical business-as-usual scenario this report chose the SSP2 scenarios which are a family of middle-of-the road scenarios used in the IPCC process. In particular, here we presented data from the SSP2-4.5 integrated scenario variant which assumes that all the greenhouse gas emissions reduction measures contained in the Nationally Determined Contributions (NDCs) under the Paris Agreement - whether conditional or non-conditional contributions - are all actually implemented in the future. SSP2-4.5 roughly corresponds to the conditional NDC scenario in UNEP's gap report 2019 which is expected to lead to an average temperature increase of 3.2°C above pre-industrial levels. This primarily due to the very large size of the global energy system.

35. Aggregate average agricultural productivity continues increasing at 0.9% per year which will be insufficient to rein in continued biodiversity loss (-3.2% in terms of the Biodiversity Intactness Index until 2050), or to eradicate food insecurity. However, rapid technological progress continues amid great socio-economic and technological divides, in some areas exacerbating them and in others closing them.

36. Human ingenuity will drive the supply and demand for entirely new technology and AI-based services, many of which will not be enhancing energy efficiencies, further increasing the global energy system size. For example, mobile video streaming uses significant energy (e.g., the system delivering Youtube videos consumed 21 TWh last year), and next generation 5G mobile networks will greatly increase the energy and climate footprint of online video streaming, as will new video gaming streaming.[36]

Comparison with worst-case scenarios

36. Worst-case scenarios and their environmental and socio-economic implications are described in detail in leading environmental assessment reports, including the IPCC and IPBES reports and UNEP's GEO. The fossil-fueled development scenario (SSP5-8.5)[37] used in the IPCC likely leads to catastrophic climate change with repercussions in all sectors and socio-economic areas. The regional rivalry scenario (SSP3)[38] is a fragmented, poor world with slow economic development, material-

objectives by 2050: Explorations using the IMAGE integrated assessment model. TFSC 98 (2015) 303–323.

[35] Folberth, C., et al. (2020). The global cropland-sparing potential of high-yield farming, Nature Sustainability vol.3, p.281–289.

[36] Chris Preist, Daniel Schien, and Paul Shabajee. 2019. Evaluating Sustainable Interaction Design of Digital Services: The Case of YouTube. In Proceedings of CHI Conference on Human Factors in Computing Systems Proceedings, Glasgow, Scotland UK, May 4–9, 2019 (CHI 2019), 12 pages. https://doi.org/10.1145/3290605.3300627

[37] Kriegler, E., et al. (2017). Fossil-fueled development (SSP5): An energy and resource intensive scenario for the 21st century. Global Environmental Change, Vol.42, Jan.2017, p.297-315.

[38] Riahi, K., et al. (2017). The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Global Environmental Change, Vol.42,

intensive consumption, worsening inequalities and 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 that is unable to deal with its larger global challenges. In one the multilateral system becomes irrelevant, whereas in the other one it is dysfunctional. Both scenarios are characterized by conflict. While there is significant technological progress, barriers to accessing knowledge and technologies persist or worsen. As a result, sustainable development progress in few areas is quickly undone by regressing in other areas, likely leading to major sustainability disasters.

IV. Issues for consideration

37. The following issues may be considered, in order to support policy making for a successful decade of action. They complement the policy issues for consideration proposed in SG report on the ECOSOC theme:

38. **Consider the long-term sustainable development implications of present decisions in response to and in support of recovery from the COVID-19 pandemic and prioritize those that increase resilience to future crises.**

39. **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.**

40. **Facilitate and prioritize investments and coordinated actions on technology efficiency, business innovations and behavioural change to rapidly increase end-use efficiency, as inspired by the LED better futures scenario.**

41. **Strengthen international cooperation on science and technology solutions for the SDGs**.

42. **Promote actor coalitions with urban citizens and farmers and consider systemic incentives, especially related to land-use, transport, and infrastructure.**

43. **Encourage business to explore new opportunities with service- oriented business models, building efficiency, granular end-use and technology innovation.**

44. **Encourage the UN system to provide coordinated capacity building support to the development of national SDG scenarios and to engage scientists and technologists, including in support of VNR preparations.**

45. **Convene scenario analysts, scientists and frontier technology experts under the Technology Facilitation Mechanism to share experiences, technology foresight and synthesize the latest knowledge on the sustainable development and SDG impacts of new technologies**.

46. **Institute a regular exchange between scenario analysts, governments science advisors and decision-makers on high impact actions for sustainable development.**

Jan.2017, p.153-168