GICA

Global Connectivity Outlook to 2030

DRAFT FOR DISCUSSION

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SIX KEY MESSAGES

1 Past trends are poor predictors. Disruptive technologies promise better connectivity, but also different forms of connectivity. Assuming a continuation of past trends in resource allocations may lead to stranded assets, for example with renewable energy and electric vehicle transforming the entire energy and transport industry. Long-term planning of infrastructure and cross-sectoral allocations need to evolve to suit the cyber and physical systems of Industry 4.0.

2 Flows will adjust towards Asia. By 2030, of a global population projected at 8.6 billion, 2 billion will be middle class and 65% of them will be in Asia-Pacific. The economic shift to Asia and its urban clusters will place a heavy need for infrastructure investments, estimated at US $1.7 trillion per year in the region.

3 Data is king. Larger than ever data flows—growing from 16 zettabytes (trillion gigabytes) annually in 2017 to 175 zettabytes by 2025 (IDC 2018)— calls fora shift towards more investment in digital capacity. The Internet of Things (IoT), Big Data analytics, Artificial Intelligence and the next generation of mobile internet will in turn enable deep disruptions in transport, energy, manufacturing, and service delivery, driven by massive investments in data infrastructure.

4 The new energy mix will impact coal and oil transport infrastructure. The pressure of climate change, combined with the ability to generate renewable energy at grid parity, store it and effectively transmit electricity over great distances will change the economics of power generation, transmission and distribution. With slower growth for coal and oil—a declining market share in an overall rapidly increasing energy demand environment, energy-related shipping may decline by up to 50% for coal and 25% for oil by 2050, limiting the need for new investments for coal/oil transport infrastructure by sea or rail.

5 Electric and autonomous vehicles are game changers. Electric vehicles will reduce the need for oil used in transport and increase transport of commodities used in batteries like cobalt and nickel. Autonomous vehicles could transform the economics of land transport. If regional agreements are reached to allow their effective movement, driverless trucks may start plying economic corridors for long trips in convoys, increasing road competitiveness compared to rail.

6 The effects of additive manufacturing are still difficult to predict. 3D printing and the digital revolution will lead to some level of re-localization and dematerialization of flows. Price may become less important for upper income groups keen on greater customization. Demand from lower and middle-income groups will remain price sensitive leading to growing flows of freight in the mid-term. Impact on total freight volume by 2030 and 2050 remains difficult to predict.

Global Connectivity Outlook Overview

The GICA Outlook is organized into four sections:

(1) An introduction to a framework for global connectivity and its levers;

(2) an outline of four megatrends that the GICA Secretariat expects to have the greatest impact on global connectivity;

(3) 17 potential disrupters, both technological and non-technological, that are inter-related but whose effects on connectivity remain uncertain, developing one way or another and possibly changing direction from expected megatrends or creating new inflection points; and,

(4) three scenarios that play out a combination of those changes and offer policy recommendations for decision makers.

This outlook prioritizes relevant information and projections (i) to help formulate policies and (ii) consider infrastructure and cross-sector allocations, as part of long-term planning. It is not meant to be exhaustive, but rather the start of a reflection for the GICA Secretariat on the impact of megatrends and disrupters on global connectivity infrastructure planning, building on analysis by its Members.

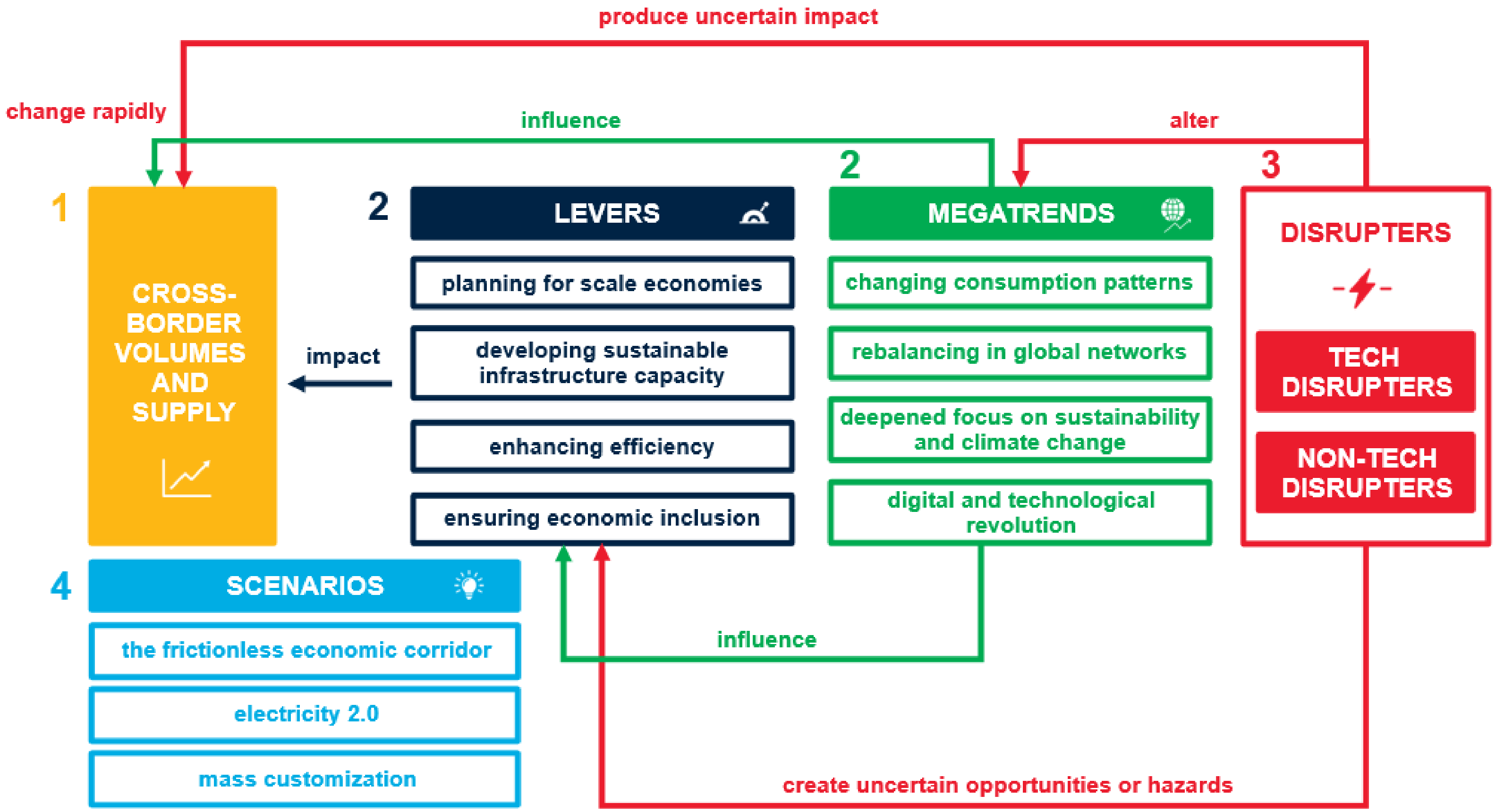
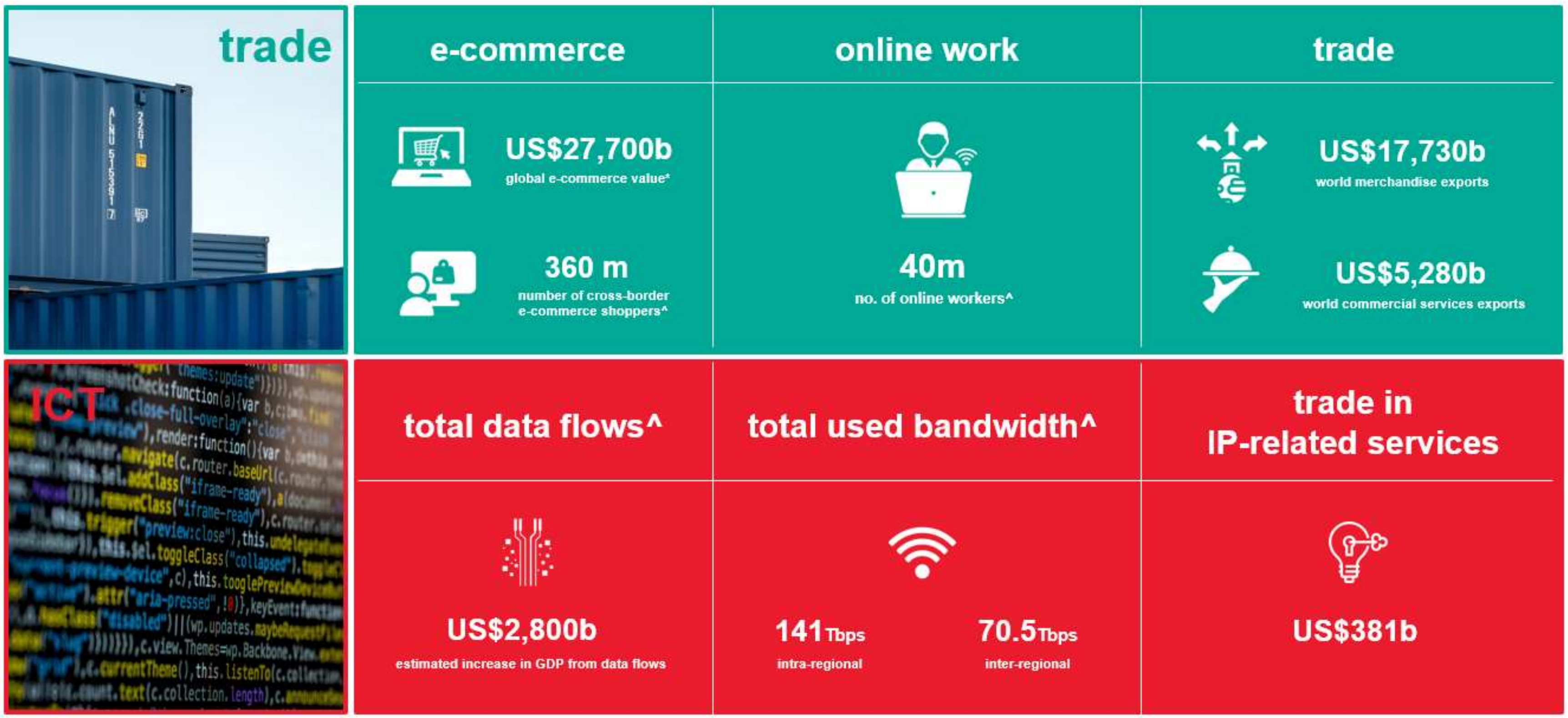


Figure 1. Outlook at a Glance
Source: GICA Secretariat

1. Current Global Flows

To understand how interconnected the world currently is, it is crucial to understand global data, material and financial flows. For this Outlook , we focus on flows related to the trade, information and communications technology, transport and energy sectors. The following infographic aims to paint a picture of how cross-border flows have become an integral part of our daily lives, and how countries can prosper from being connected with others.



Note:

1. Unless otherwise stated, all figures are the latest from year 2017.
   - * Figure is as of 2016
   - ~ Figure is as of 2015
   - ^ Figure is as of2014
2. Unless stated otherwise (by **+**), all the figures in the infographic above reflect cross-border flows.
3. Terminologies used in the infographic as defined by the respective organizations.
4. Readers are strongly advised to refer to the sources of the data (provided in Annex A) for the most updated data available.
5. The artwork shown above is created by Chi Fung, Fan for the GICA Secretariat.

2. Levers for Global Infrastructure Connectivity

Global infrastructure connectivity refers to the physical linkages of communities, economies and nations through transport, communications, energy, and water networks across borders. It incorporates associated services that are inseparable -- in trade, logistics, human mobility, and information -- from the underlying infrastructure to improve the flow of goods, people and data. Connectivity measures the extent to which the components of a network (links and nodes) are connected to one another, and the ease (speed, cost and reliability) with which they can interact.

Technologies are converging in new ways and will change how people connect, interact, and exchange goods and services. The pace of transformation is rapidly and continuously accelerating under the effects of disruptive technologies. The World Bank Development Committee defines disruptive technologies as emerging technologies that result in a steep change in the cost of, or access to, products or services, or that dramatically change how we gather information, make products, or interact. Such disruptive innovation emerges from the margins to offer novel, easier, and often cheaper solutions to old problems.

A range of technologies have the potential for far-reaching impact on development, such as new energy transmission technology and rapid renewable energy advances, artificial intelligence (AI), advanced robotics, autonomous vehicles (AV), big data and analytics, blockchain, cloud technology, drones, fifth or next generation mobile network (5G), the Internet of Things (IoT), or 3D printing.[1]

Emerging disruptive technology, as well as other non-technological disruptions, will have significant impact on global connectivity. Better, real-time data enables improved analysis of connectivity supply and demand. New digital platforms can scale up quickly and cross borders to serve new markets. Efficiency gains occur by leaps and bounds, significantly reducing costs and vastly improving connectivity.

Disruption poses challenges for meeting infrastructure needs. For instance, corridors, regions and urban centers will have greater infrastructure demands, while rural areas will face growing aspiration gaps. Greater synergy between sectors is needed—for example, coordinating the roll-out of fiber network with road construction, in particular to address “first mile” and “last mile” connectivity challenges in transport, economic opportunity, internet access, electrification and internet access. Serious gaps in financing, technology and regulatory frameworks remain, although the emergence of a large private investment pool targeted at infrastructure, including existing international financial institutions (IFIs) and new institutions like the Asian Infrastructure Investment Bank (AIIB), and initiatives like the Belt and Road Initiative (BRI) offer opportunities to address some of those gaps.

[1] World Development Report 2016 “Digital Dividends”, Washington DC: The World Bank, 2016, p. 326-330. Also https://worldbankgroup.sharepoint.com/sites/wbsites/DisruptiveTechnologies/Pages/Home_New.aspx

In order to manage infrastructure connectivity, supply and demand, GICA has developed a connectivity framework that hinges on four levers (see Figure 2 below): ***Planning for scale economies*** by fostering agglomeration or concentration of activities, leading to unit cost savings, accelerated innovation and leveraging of comparative advantages (e.g. hydropower traded within a region); ***Developing sustainable infrastructure capacity*** by addressing missing links and bottlenecks in networks, enhancing system resilience, and improving capacity; ***Enhancing efficiency*** by addressing frictions in service delivery both within the industry and at border crossing points; and ***Ensuring economic inclusion*** by connecting lagging regions and communities.

	Connectivity: Improving the Flow of Goods, People, and Data			
	Focus on Impacts, Flows, Replicable Mechanisms, Measures of Success, Integration			
GICA Levers	**Planning for Scale Economies**	**Developing Sustainable Infrastructure Capacity**	**Enhancing Efficiency**	**Ensuring Economic Inclusion**
Key Components	• **Foster agglomeration** • Economic corridors • Cluster development • Logistics zones • Inland clearance depots • **Develop hub and spoke systems** • **Leverage comparative advantage (hydropower..)**	**Across sectors (transport, ICT, power & water):** • Develop missing links and nodes • Upgrade capacity • Embed resilience and greening considerations	• **Harmonize legal & regulatory framework** • **Modernize border and customs management** • **Facilitate service diversity, competition & integration** • **Enhance transit management**	• **Connect lagging regions** • **Enhance connectivity for small holders, SMEs and poor households** • **Leverage broadband digital connectivity**
How	**Regional planning for synergies across regional markets, investment promotion aligned with regional plans**	**Master-planning based on demand and regional plans, prioritization, cross border mechanisms for sharing costs/benefits**	**Agreements, audits & reengineering of business processes, automation, shared e-platform for trade and logistics, regulations**	**Public investment and PPP mechanism to enhance universal access**
	Policy, legal and regulatory framework, strategies, institutional arrangements, capacity building, public private dialogue, public and private financing cascade, measurement & evaluation using big data/data analytics			

Figure 2. The GICA Connectivity Framework
Source: Ollivier and Schwartz (2017)

Infrastructure Trade-Offs and Synergies

The pursuit of improved global infrastructure connectivity is built on the importance of such linkages in spurring economic growth and job opportunities, greater access to basic services and markets, enhanced resilience, and reduced vulnerability to shocks and to climate change-induced events. While endowments like distance and geography are fixed, connectivity and logistics performance can be altered through policy-making.[2] But decisions can also be fraught with trade-offs between one dimension, say gaining efficiency, and another, like providing access, often to the detriment of the environment or marginalized social groups. Network resilience to natural events and cyber-attacks are redefining likewise network planning by emphasizing components of network criticality over network efficiency[3]. Planning with a constrained set of resources allocations for one type of infrastructure also impacts resources available for others.

Infrastructure sharing can thus play a key role both for scale economies in the development of infrastructure corridors and for economic inclusion. Asset sharing in competitive environments can bring connectivity to previously unconnected geographical areas which would otherwise be economically unviable to serve if infrastructure had to be duplicated.[4]The Association for Progressive Communications estimates that an operator can save up to two-thirds of the costs of the deployment of a greenfield fiber network by sharing network roll-out with two other operators.[5] Cross-sectoral infrastructure sharing can allow the same operator to avoid almost all of the costs associated with civil works. In fact, coordinating the roll-out of a fiber network with road construction adds just 0.9 to 2 percent to the total costs of the road.[6] Infrastructure sharing can also generate positive environmental benefits. According to a study by Huawei and Telecom Italia in 2010, the annual carbon footprint of fiber networks can be reduced by up to 36 percent if the network has been deployed utilizing existing infrastructure.[7]

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[2]"Why Connectivity Matters," GICA, https://www.gica.global/sites/gica/files/Discussion-Paper-Why-Connectivity-Matters-May-10-2018.pdf, pg. 9.

[3] Gould David Michael," Critical Connections, Promoting Economic Growth and Resilience in Europe and Central Asia" 2018, Washington DC: World Bank. https://www.gica.global/resources/critical-connections-promoting-economic-growth-and-resilience-europe-and-central-asia

[4]Deloitte LPP, and Association for Progressive Communications, "Unlocking Broadband for All: Broadband Infrastructure Sharing Policies and Strategies in Emerging Markets," Association for Progressive Communications, April 2015. https://www.apc.org/en/node/20382, pg. 6.

[5]*Ibid*., pg. 5.

[6]*Ibid*.

[7]*Ibid*., pg. 38.

Megatrends

Global megatrends are deep trends, well underway, that exert a persistent impact on governments, the economy and society. Such trends determine the long-term planning and future investments in connectivity infrastructure, estimated at US$49 trillion to serve annual growth from 2016 to 2030.[8]

We know with some certainty that the megatrends will happen or are already occurring, and they help paint a picture of the future.[9] Governments, businesses and society can anticipate the outcome and strategize based on linear and probabilistic projections and predictions of growths, declines and other prospects on the horizon. Based on research forecasts, the GICA Secretariat focuses on four megatrends with profound impact on global connectivity: changing consumption patterns, rebalancing in global networks, deepened focus on sustainability and climate change, and accelerating digital and technological revolution.

Changing Consumption Patterns

The world's population is expected to reach 8.6 billion in 2030.[10]The approximately 2 billion people who will attain middle class status by 2030 will shape and create new demands for global connectivity, and the most likely source of these new demands will come from the burgeoning economies of Asia and the Pacific. Cities in particular will play a central role.

Benefiting from their country's economic growth, the new middle class is likely to demand more goods and services, impacting transportation systems and their ability to handle high volumes of goods efficiently. The new middle class will seek higher-value, internationally sourced manufactured goods or goods customized to their preference, in order to match their newfound social status instead of low-cost, locally mass-manufactured products. Their consumption of online content and use of e-commerce will grow dramatically. The demand for outbound travel is also likely to increase, as regions see a rise in GDP per capita. According to estimates by Brookings Institution, global middle-class spending will almost double from the US$35 trillion annually in 2015 to US$64 trillion in 2030.[11]

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[8]Woetzel, Jonathan, Nicklas Garemo, Jan Mischke, Martin Hjerpe, and Robert Palter, "Bridging Global Infrastructure Gaps," McKinsey Global Institute, accessed November 15, 2018,https://www.mckinsey.com/industries/capital-projects-and-infrastructure/our-insights/bridging-global-infrastructure-gaps.

[9]Adapted from Tilmes, Klaus, and Naoto Kanehira, "Perspectives on Disruptive Technologies and Forces," accessed November 11, 2018.http://pubdocs.worldbank.org/en/108081526003752002/051118-disruptive-technology-seminar-Tilmes-Klaus.pdf.

[10]United Nations, "World Population - Projected World Population until 2100," accessed October 18, 2018. https://www.un.org/development/desa/publications/graphic/wpp2017-global-population.

[11]Kharas, Homi, "The Unprecedented Expansion of the Global Middle Class - An Update," Brookings Institution, February 2017. https://www.brookings.edu/wp-content/uploads/2017/02/global_20170228_global-middle-class.pdf, pg. 15.

Rebalancing in Global Networks

Following decades of rapid growth, the pace of globalization appears to be slowing structurally, with a decline in the growth of parts and components trade and a shift in its center of gravity towards Asia. Annual global trade growth has been subdued at around 3 percent since 2011[12], far below the pre-crisis annual average of 7 percent from 1987 to 2007. Despite the guarded outlook on global trade, trade partnerships among different sets of countries continue to grow. These trade partnerships will be further strengthened by regionalization, as regional connectivity initiatives such as the Master Plan on ASEAN Connectivity 2025 increase the inter-connectedness and interdependence among countries located within proximity of one another. In turn, regional integration, through agreements like the Regional Cooperation Economic Partnership (RCEP) is expected to enable countries to respond to and rebound from external shocks collectively, thereby increasing the region's overall resilience.

According to the Asian Development Bank, the region's share of global GDP grew from 30.1 percent in 2000 to 42.6 percent in 2017, at 2011 purchasing power parity (PPP) (see Figure 3).[13] China, India and Japan combined accounted for more than 70 percent of the region's 2017 GDP at PPP.[14] This trend is expected to continue, with the region contributing to more than half of global GDP by 2050.[15]

The region's growth potential coincides with that of its middle class. According to Brookings Institution scholar Homi Kharas, Asia and the Pacific will be home to 65 percent of the global middle class[16] and account for over 57 percent of global middle-class spending in 2030.[17]Asia and the Pacific accounted for 317 million outbound visitors in 2016 (an 8 percent increase from 2015) and generated almost 40 percent of the world's tourism expenditures (US$473 billion).[18] China alone accounted for 55 percent of Asia's outbound expenditure, and generated 21 percent of global tourism receipts.[19]As such, Asia's middle class will become the world's biggest spenders in 2030[20](See Figure 4).

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[12]World Trade Organization, "World Trade Statistical Review 2018," accessed November 12, 2018. https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018_e.pdf, pg. 28.
[13]Asian Development Bank, "ADB Releases 2018 Flagship Statistical Report for Asia and the Pacific," September 10, 2018. https://www.adb.org/news/adb-releases-2018-flagship-statistical-report-asia-and-pacific.
[14]Asian Development Bank, "Key Indicators for Asia and the Pacific 2018," Asian Development Bank, September 2018. https://www.adb.org/sites/default/files/publication/443671/ki2018.pdf, pg. 93.
[15] Asian Development Bank,*Asia 2050 - Realizing the Asian Century (Executive Summary),* Asian Development Bank, 2011. https://www.adb.org/sites/default/files/publication/28608/asia2050-executive-summary.pdf, pg. 3.
[16]Kharas, Homi, "The Unprecedented Expansion of the Global Middle Class - An Update," Brookings Institution, February 2017. https://www.brookings.edu/wp-content/uploads/2017/02/global_20170228_global-middle-class.pdf, pg. 13.
[17]*Ibid.*, pg. 15.
[18]World Tourism Organization, and Global Tourism Economy Research Centre, "Asia Tourism Trends 2017 Edition (Executive Summary)," World Tourism Organization, 2017. https://www.e-unwto.org/doi/pdf/10.18111/9789284419142, pg. 6.
[19]*Ibid.*, pg. 7.
[20]Barua, Akrur, "Packing a Mightier Punch: Asia's Economic Growth Among Global Markets Continues," December 18, 2015. https://www2.deloitte.com/insights/us/en/economy/asia-pacific-economic-outlook/2016/q1-asia-economic-growth-continues.html.

In the same vein, Central America, South America, Africa and the Middle East combined are also expected to be home to 15% of the world's middle class and account for 13% of global middle-class spending in 2030.[21] Click here for more

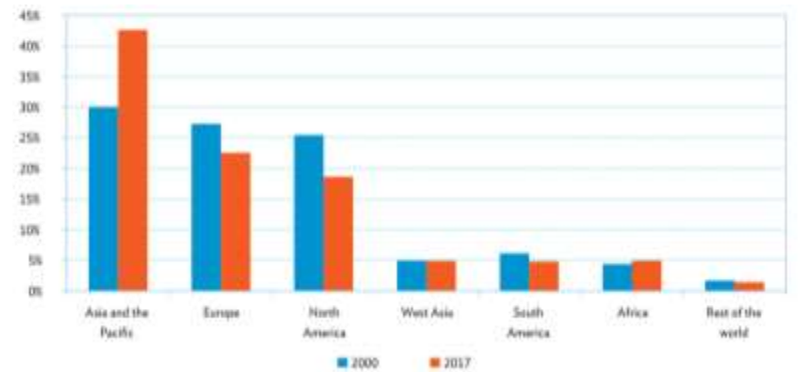

Figure 3: Asia and the Pacific's Share of 2017 Global GDP at 2011 Purchasing Power Parity (%)
Source: Asian Development Bank

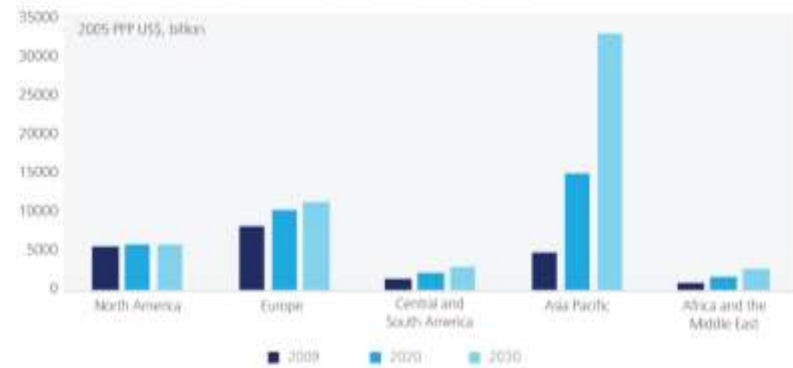

Figure 4: Projections of Middle Class Spending in 2020 and 2030 by Region
Source: Deloitte[22]

The allure of regionalization is evident in trade statistics. As of May 2018, 287 physical regional trade agreements (RTAs) are in force, with Europe and East Asia accounting for over 63 percent of global RTAs (Figure 5).[23] Unsurprisingly, the European Union is the most dynamic RTA, accounting for 34.3 percent of world's exports in 2017 (Figure 6).[24]

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[21]Kharas, Homi, "The Unprecedented Expansion of the Global Middle Class - An Update," Brookings Institution, February 2017. https://www.brookings.edu/wp-content/uploads/2017/02/global_20170228_global-middle-class.pdf, pg. 14 – 15.

[22]Originally published in Akrur Barua, *Packing a mightier punch: Asia's economic growth among global markets continues*, Deloitte Insights, December 18, 2015.

[23]World Trade Organization, "Regional Trade Agreements Information System (RTA-IS)," accessed October 18, 2018. http://rtais.wto.org/UI/PublicMaintainRTAHome.aspx.

[24] World Trade Organization,"World Trade Statistical Review 2018," World Trade Organization, accessed October 18, 2018. https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018_e.pdf,pg. 18.

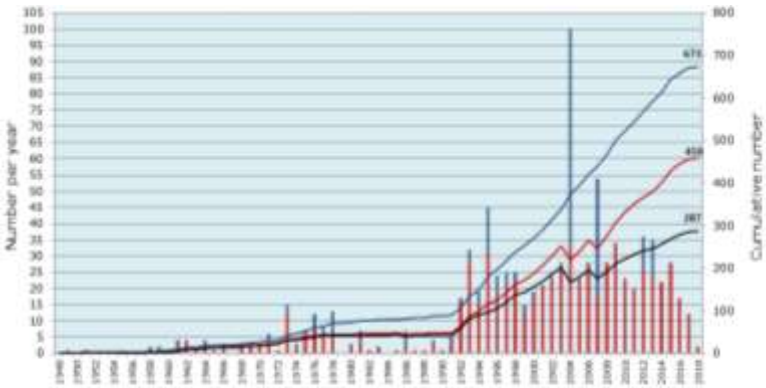

Figure 5: The Evolution of Regional Trade Agreements (RTAs)
Source: [World Trade Organization](#)

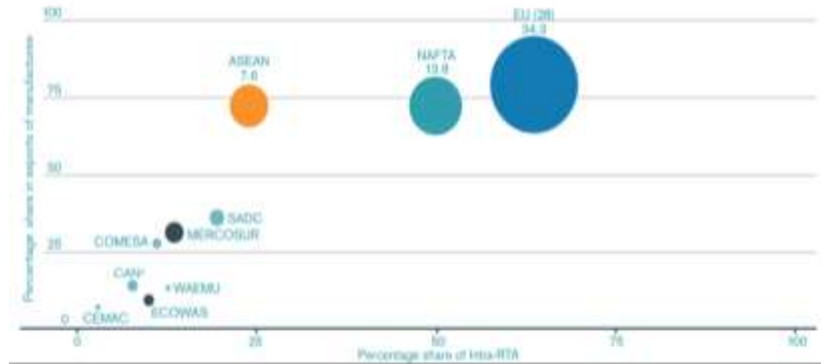

Figure6: RTA Share in Global Exports of Manufactured Goods and in Intra-RTA Trade
Source: [World Trade Organization](#)

In addition, as a country progresses up the global value chain, new trading opportunities will open up for other countries. For example, the shifting of low-cost manufacturing activities from China to neighboring East and South Asian countries could generate additional seaborne trade flows.

Cities will shape the dynamics of international trade as the key engines of wealth creation and innovation in this century. They already generate more than 80 percent of global GDP.[25] And as the current global population increases by1 billion by 2030,[26] with as many as 60% living in urban areas by 2030 (Figure 7),[27] cities are likely to only grow as economic epicenters of global trade activities.

In the future, global economic growth may be driven by three types of cities (that are not mutually exclusive), namely: (i) global hubs such as Singapore, London and New York through which much of the world's wealth and talent flow; (ii) mega-cities such as Mumbai, Jakarta and Sao Paulo as large populous magnets for their respective regions; and (iii) gateway cities such as Dubai, Almaty and Johannesburg which are regional clusters that facilitate access to frontier markets.[28] As in China, cities are likely to be reorganized around city hubs to form urban agglomerations

[25] World Bank Group. "World Bank Urban Development," October 5, 2018. http://www.worldbank.org/en/topic/urbandevelopment/overview.
[26] United Nations, "World Population Projected to Reach 9.8 Billion in 2050, and 11.2 Billion in 2100," June 21, 2017. https://www.un.org/development/desa/en/news/population/world-population-prospects-2017.html.
[27] Smith, Duncan, "Mapping the Global Urban Transformation," December 9, 2015. https://citygeographics.org/2015/12/09/mapping-the-global-urban-transformation/.
[28] Khanna, Parag, "When Cities Rule the World," February 2011. https://www.mckinsey.com/featured-insights/urbanization/when-cities-rule-the-world.

that can take advantage of the sheer size of the markets. Cities, however, will contend with increasing congestion as they grow in size and continue to attract greater levels of economic activity, requiring infrastructure investments to address these challenges. [Click here for more](#).

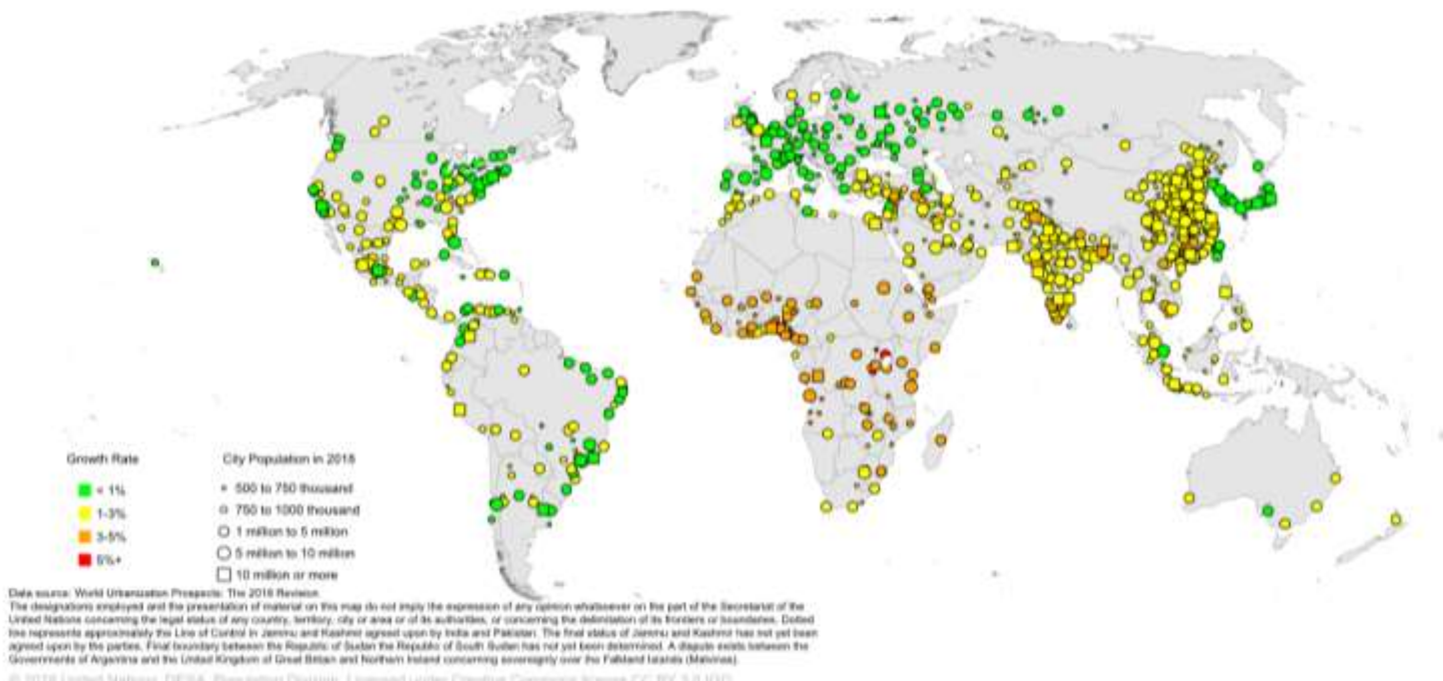

Figure 7: Growth Rates of Urban Agglomerations by Size Class, 2018 to 2030 Projections
Source: [United Nations](#)

Connectivity needs will reflect the economic shift to Asia and its urban clusters, as well as growing regionalism.

While agglomeration economies will make the world more prosperous overall, such rebalancing risk to exacerbate spatial inequalities, given the capital intensity of the related infrastructure and technological solutions. Ensuring last and first mile connectivity and digital competencies for the population, as a whole, will become a growing priority for social equity.

Deepened Focus on Sustainability and Climate Change

Threats to the environment and climate will continue to rise, if the current trends – population growth, ecosystem overexploitation, and unsustainable consumption and production patterns – continue unabated.

The Intergovernmental Panel on Climate Change recently warned that limiting global warming to 1.5°C could avoid a number of climate change impacts compared with the 2°C limit agreed upon in the 2015 Paris Agreement. The impacts and costs of global warming on ecosystems, human health and well-being as a result of global temperature increase will be far greater than expected, unless the world truly embraces sustainable and responsible growth.[29]Climate change will adversely affect international trade, through growing disruptions to supply, transport and distribution chains, causing delays and higher costs of international trade. Some companies may shift to alternatives to increase the reliability of their supply chains. Furthermore, the negative impacts of climate change will not be experienced evenly across the globe. Continued environmental degradation runs the risk exacerbating spatial inequality.

According to OECD estimates, annual GDP losses could amount to between 1.0 to 3.3 percent by 2060 depending on how much global temperature would rise (Figure 8).[30] In the same vein, the volume of international trade is projected to be negatively affected, with lower global exports (-1.8%) and imports (-1.6%) compared to a baseline without climate change.[31] The impact of those effects is expected to be felt within the life of new infrastructure assets, even if the bulk of changes is expected post 2030.

[29] Intergovernmental Panel on Climate Change. "Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C Approved by Governments." Intergovernmental Panel on Climate Change, October 8, 2018. https://www.ipcc.ch/pdf/session48/pr_181008_P48_spm_en.pdf, pg. 1.
[30] Dellink, R., et al. (2017), "International trade consequences of climate change", OECD Trade and Environment Working Papers, No. 2017/01, OECD Publishing, Paris, https://doi.org/10.1787/9f446180-en, pg. 23.
[31] *Ibid.*, pg. 28.

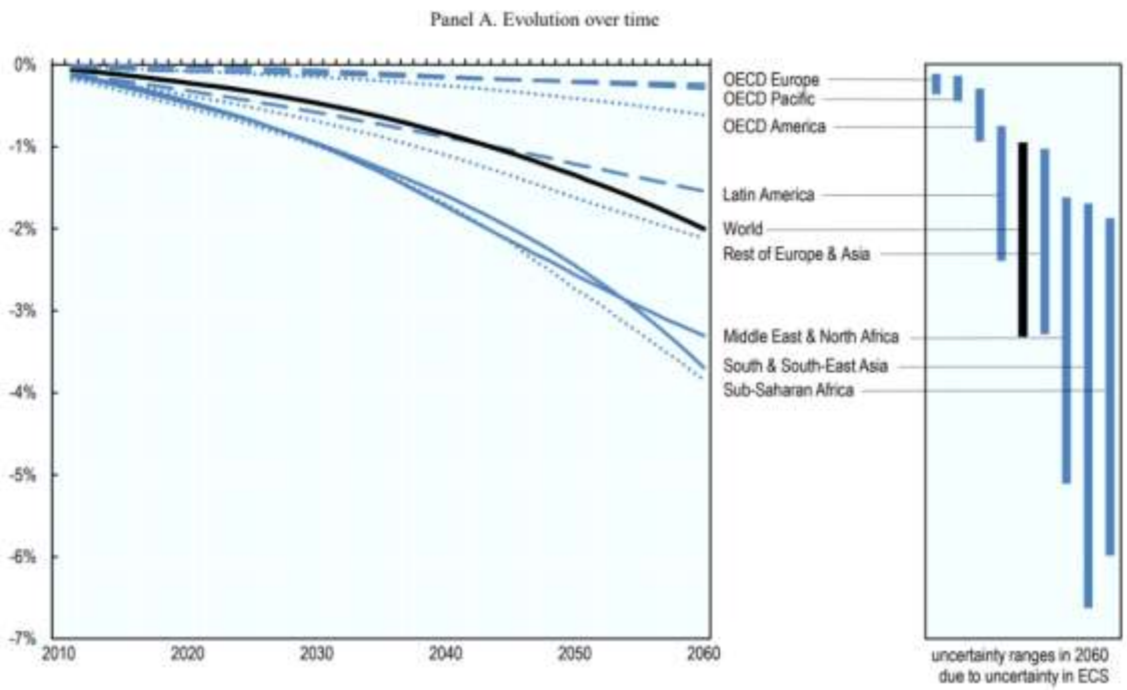

Figure 8: Percentage of Change in GDP with respect to No-Damage Baseline
Source: OECD

To meet climate targets, the energy intensity of the global economy will have to fall by about two-thirds by 2050. The power sector has made significant progress in recent years, but the transport, industry and construction sectors need to improve.[32] Being the least diversified energy end-use sector, the transport sector has witnessed the fastest emissions growth over any other sectors over the last century. It accounted for 28 percent of global final-energy demand and 23 percent of global energy-related carbon dioxide (CO_2) emissions in 2014.[33]If no additional measures are taken, CO_2 emissions from global freight could increase by 160 percent, as the international freight volumes grow threefold during the same

[32] International Renewable Energy Agency, "Global Energy Transformation: A Roadmap to 2050," Abu Dhabi: International Renewable Energy Agency,accessed October 18, 2018. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf, pg. 10.
[33] Rogelj, Joeri, Drew Shindell, and Jiang Kejun, "Chapter 2: Mitigation Pathways Compatible with 1.5C in the Context of Sustainable Development," Intergovernmental Panel on Climate Change, June 4, 2018. http://report.ipcc.ch/sr15/pdf/sr15_chapter2.pdf, pg. 2-66.

period.[34] The industry sector is the largest end-user sector in terms of both final-energy demand and greenhouse gases emissions. Its direct CO_2 emissions currently account for about 25 percent of total energy-related and process CO_2 emissions, and have increased with an average annual rate of 3.4 percent between 2000 and 2014.[35] Energy demand in the industry sector is projected to increase by more than 40 percent between 2010 and 2050, and CO_2 emissions would increase by 30 percent in 2050, if nothing is being done to curb global warming.[36]Click here for more.

Looking forward, growing awareness of the consequences of climate change, combined with aspirations to curb air pollution in most of the developing world (withCO_2 emission reductions as a co-benefit) is anticipated to lead to a shift towards more sustainable power, transport and industrial solutions. This will impact some of the infrastructure which traditionally has been developed to support a fossil fuel economy.

Digital and Technological Revolution

Technologically-driven disruption is not new for the global trade system. The invention of steam engines first transformed the way goods were produced and people and goods were transported over longer distances within a shorter time frame. The most recent major disruption occurred when computers and the Internet were invented, replacing analog electronic and mechanical devices. Digital technology is heralding the next phase of disruption to the global economy, with the emergence of new technologies like blockchain, additive manufacturing, big data analytics, the Internet of Things and Artificial Intelligence. They will not only transform the global economy by constantly redefining consumer expectations and business models, but also engender inclusiveness by providing an avenue through which people can access opportunities and interact with one another.

Even if the precise impact of disruptive technology is uncertain, there is no doubt that digital technology will form the backbone of connectivity in the world of 2030. It is estimated that there will be 5 billion mobile Internet users (a 61 percent penetration rate) and 5.9 billion unique mobile subscribers (a 71 percent penetration rate) in 2025.[37] By then, the number of digital devices worldwide may be three times the number of people with 60 percent of mobile traffic in the Asia-Pacific, the Middle East, and Africa.

Digital technology will also play a crucial role in international trade. The United Nations Conference of Trade and Development (UNCTAD) estimates that the production of information and communication (ICT) goods and services was responsible for approximately 6.5 percent of global

[34]Organisation for Economic Co-operation and Development, “ITF Transport Outlook 2017,” January 30, 2017. http://www.oecd.org/about/publishing/itf-transport-outlook-2017-9789282108000-en.htm, p.13.
[35]Rogelj, Joeri, Drew Shindell, and Jiang Kejun, “Chapter 2: Mitigation Pathways Compatible with 1.5C in the Context of Sustainable Development,” Intergovernmental Panel on Climate Change, June 4, 2018. http://report.ipcc.ch/sr15/pdf/sr15_chapter2.pdf, pg. 2-60.
[36]*Ibid.*, pg. 2-63.
[37] GSM Association, “The Mobile Economy 2018 Infographic,” accessed October 18, 2018. https://www.gsma.com/mobileeconomy/wp-content/uploads/2018/02/Mobile-Economy-Global-2018-Infographics.pdf.

GDP in 2015, with the value added of ICT services estimated to be about US$3.2 trillion and the value added of ICT goods estimated to be about US$1.7 trillion.[38] Globally, e-commerce sales, enabled by the digital economy, was estimated to amount to US$25.3 trillion in 2015 (Figure 9).[39] Global trade in ICT goods in 2015 exceeded US$2 trillion.[40] By 2025, digital technologies have the potential to increase world GDP by $2.7 trillion and create full-time employment for 72 million people.[41]Click here for more.

	Economy	Total		B2B		B2C
		$ billion	Share in GDP (per cent)	$ billion	Share in total e-commerce (per cent)	$ billion
1	United States	7 055	39	6 443	91	612
2	Japan	2 495	60	2 382	96	114
3	China	1 991	18	1 374	69	617
4	Republic of Korea	1 161	84	1 113	96	48
5	Germany (2014)	1 037	27	944	91	93
6	United Kingdom	845	30	645	76	200
7	France (2014)	661	23	588	89	73
8	Canada (2014)	470	26	422	90	48
9	Spain	242	20	217	90	25
10	Australia	216	16	188	87	28
	Total for top 10	**16 174**	**34**	**14 317**	**89**	**1 857**
	World	**25 293**	..	**22 389**	..	**2 904**

Figure 9: Total Value of E-commerce Sales in 2015
Source: United Nations Conference of Trade and Development

[38]United Nations Conference on Trade and Development, "Information Economy Report 2017: Digitalization, Trade and Development," United Nations Conference on Trade and Development,accessed October 18, 2018. https://unctad.org/en/PublicationsLibrary/ier2017_en.pdf, pg. 22.
[39]*Ibid.*, pg. 27.
[40]*Ibid.,* pg. 16.
[41]*Ibid.*, pg. 50.

Disruptions

Key shifts in consumption patterns, the importance of regions and cities, sustainability and climate change, and digital technology drive long-term planning for connectivity infrastructure provision. However, technological changes and other driving forces are occurring rapidly with uncertain, potentially disruptive effects. While megatrends are the big changes already underway that have predictable effects, disrupters may force drastic changes to these expectations. Apart from being better, cheaper, faster and easier than the norm, these new technologies also accelerate innovation in combination with one another, scale up quickly and diffuse globally.[42]How can we leverage on the positive potential of disruption? How can we mitigate the risks?

The GICA Outlook offers a framework for decision makers to:

- recognize the potential disruptions that will transform the ways we connect;
- consider some plausible scenarios of how these transformations will have an impact on connectivity supply and demand;
- formulate policy options that recognize critical interventions (investment, regulation) that will be necessary to achieve the goals of enhanced connectivity, harnessing the positive potential of disruption; and,
- apply this perspective and strategies to real decision making.

The GICA Outlook identifies potential disrupters, describing each in terms of projected ***size of impact*** on connectivity, the ***nature*** of the disrupter (tech and non-tech disruption), the potential ***changes in volume*** of human mobility, trade, energy and data, and the possible ***timeframe*** in which the disrupter will begin to have a significant impact. The diagram below depicts disrupters, impact on connectivity and time. This preliminary assessment is based on existing research and published projections. This analysis is meant to launch discussions with relevant experts and be further refined.

This report presents scenarios *in 2030* and policy options *today* for three case studies:

1. "Frictionless Economic Corridor" – autonomous trucks in economic corridors
2. "Electricity 2.0"[43] – smart grids, batteries and long-distance transmission for solar and wind generation in local and regional power pools
3. "Mass Customization" – additive manufacturing in global and local value chains

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[42] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 3.
[43] The term "electricity 2.0" is adapted from Tom Raftery

Each case presents an overview of the challenge, elaborates a summary outlook to 2030 including the possible development of highly relevant technology, key regulatory issues, and how connectivity may be affected. Key uncertainties are identified, and a corresponding set of plausible scenarios and policies are formulated for decision makers.

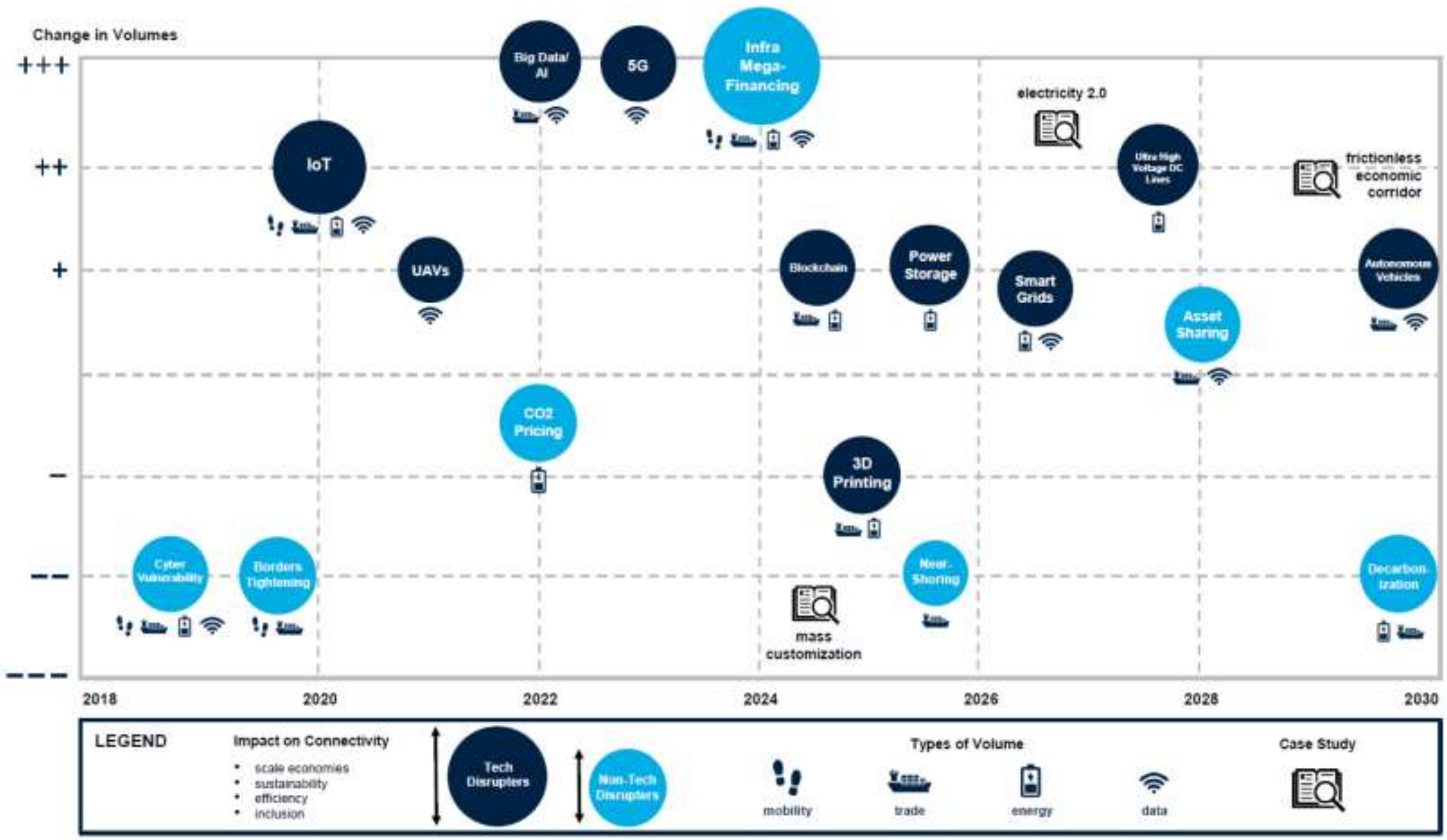

Figure 10: Diagram on Disruption and Global Connectivity
Source: GICA Secretariat (schematic by Sol Iglesias and Chi Fung, Fan)

Disrupters

Disrupters are factors with potentially high impact on connectivity by 2030 but, unlike megatrends identified above, are less predictable in the short- to medium-term. The idea originated in an influential 1997 study which found that disruptive innovation emerged from the margins to offer customers easier and simpler solutions, allowing smaller rivals to topple industry leaders.[44] Since then, disruption has come to mean new solutions to old market problems. Moreover, many of these new technologies or processes are cheaper than their older equivalents, they spread more rapidly around the world due to falling costs and internet connectivity, and they offer greater scalability.[45] The World Bank, for instance, has identified a range of technologies that promise to have far-reaching impact on development.[46]

The set of disrupters analyzed here is not exhaustive but is expected to capture the main disruption on connectivity to be considered in policy and investment discussions with stakeholders in governments, the private sector and civil society. It will need regular updates, considering the rapid emergence of new disrupters.

Tech Disrupters

Tech disrupters can be: (1) *informational*, changing how we collect, store, access, analyze and present data for greater efficiency and responsiveness to user needs; or (2) *production*-related, changing manufacturing, distribution, transmission, transport and logistics techniques to improve efficiency, lower cost and increase speed.[47] Tech disruption faces uncertain regulatory environments, both globally and locally, and market responses can be difficult to predict.

Non-tech Disrupters

Non-tech disrupters are organizational processes implemented by public institutions, consumers, social groups and businesses, transforming how people interact with the world and deliver or receive services, and can be categorized as: (1) *policy/regulatory disrupters*, which are government interventions to promote, disincentivize or end certain practices, including through investment or divestment; or (2) *social/business disrupters*, which pertain to business practices driven by consumer preferences and market signals.[48]

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[44] Christensen, Clayton M, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*, Cambridge, MA: Harvard Business School Press, 1997.

[45] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 3.

[46] World Bank Group, "World Development Report 2016: Digital Dividends," accessed October 28, 2018.http://www.worldbank.org/en/publication/wdr2016, pg. 326-330. Also https://worldbankgroup.sharepoint.com/sites/wbsites/DisruptiveTechnologies/Pages/Home_New.aspx.

[47] World Bank, Transport & Digital Development Townhall "Realizing the Transport We Want" (slide deck), 2018.

[48] Adapted from Deutsche Post DHL Group, "2018/2019 Logistics Trend Radar," accessed October 12, 2018. http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/trendradar.html#.W2QjBjKFM2w.

Impact on Connectivity

These disrupters can have a potential impact on connectivity that varies by magnitude, with an impact through four levers of connectivity: (1) planning for scale economies, with an emphasis on corridors, local development and regional integration; (2) developing sustainable infrastructure capacity; (3) enhancing efficiency; and(4) ensuring economic inclusion.

Change in Volumes

Disrupters may have an impact on trade volumes, cargo mobility, passenger mobility, energy consumption and data usage. Abrupt changes—whether escalation, a precipitous fall, or volatility—may stress out or strand infrastructure capacity. The expected volume impact is recorded on the y-axis of the graph.

Case Study Dynamics

Disruption and connectivity do not exist in a vacuum—they are part of a dynamic and changing environment and the interplay of multiple disrupters. The early development of some disrupters, for instance the next generation of mobile internet or 5G, will enable internet-based technologies and affect many other disrupters. The extent and quality of internet access will affect scenarios in the following decade across different sectors such as energy (Electricity 2.0 case study), manufacturing (Mass Customization case study) and transport (Frictionless Corridor case study). In each case study, up to four scenarios were analyzed. This outlook focuses on one selected scenario per case study, chosen for its plausibility and potential impact on connectivity.

The analysis offers qualitative insights on how the four levers of connectivity can be affected. These are not predictions but rather they can help anchor policy discussions on how to promote connectivity and mitigate risks. The time frame for analysis starts in 2018 and ends around 2030 but this is not a strict endpoint. The inter-relationships between disrupters and their potential impact on connectivity are explored in greater detail through case study analysis.

Informational

1. Internet of Things (IoT)

IoT may be defined as a system that involves "connected devices that gather data, connect with the Internet or local networks, generate analytics, and (in some cases) adapt behavior/responses based on the data/analytics in the network."[49]

IoT has a total potential economic impact of US$3.9 trillion to US$11.1 trillion per year by 2025.[50]This estimate includes US$560 to US$850 billion that may result from changes in logistics routing, autonomous cars, trucks and navigation, US$210 to US$740 billion from vehicles' condition-based maintenance and US$1.2 to US$3.7 billion in manufacturing. IoT is needed to improve energy efficiency, especially for renewables. IoT is expected to comprise 2 to 5% of all internet traffic by 2021.[51]

Timeframe: <5 years |Volumes changed: mobility, trade, energy, data| Size of Impact: high | Connectivity Levers: efficiency

2. Big Data Analytics & Artificial Intelligence (AI)

Big Data Analytics refers to the process of automated data analysis to draw conclusions about the information they contain and make decisions, with the aid of specialized systems and software. This process is enhanced with Artificial Intelligence, learning from Big Data, facilitated by cloud computing and advanced microprocessors.[52]Data is predicted to grow from around 16.1 zettabytes (a zettabyte is one trillion gigabytes) in 2016 to 163 zettabytes in 2025.[53]The proliferation of big data and artificial intelligence will usher the world into a new era of "intelligent" connectivity. Employing Big Data and AI can increase the efficiency of infrastructure connectivity. AI has the potential to create annual economic value of between US$3.5 trillion and US$9.5 trillion.[54]

Timeframe: <5 years | Volumes changed: trade, data | Size of Impact: high | Connectivity Levers: efficiency

3. Next generation/5G Mobile Network

5G refers to the next or 5th generation of mobile wireless technology, which promises much faster data transfer speeds and lower latency. Set to roll out within the

[49]Lal Das, Prasanna; Beisswenger, Stefan Claus; Mangalam, Srikanth; Yuce, Mehmet Rasit; Lukac, Martin. 2017. *Internet of things : the new government to business platform - a review of opportunities, practices, and challenges (English)*. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/610081509689089303/Internet-of-things-the-new-government-to-business-platform-a-review-of-opportunities-practices-and-challenges, pg. 25.

[50]United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg.9.

[51] Stephanie Condon, "Report: IoT to dominate connected device landscape by 2021", *ZDNet,* June 8, 2017, https://www.zdnet.com/article/report-iot-devices-to-dominate-connected-device-landscape-by-2021/.

[52]United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 8.

[53] David Reins, John Gantz, John Rydning, *Data Age 2025: The Evolution of Data to Life-Critical*, IDC, April 2017. https://www.seagate.com/files/www-content/our-story/trends/files/Seagate-WP-DataAge2025-March-2017.pdf.

[54]Chui, Michael, James Manyika, Mehdi Miremadi, Nicolaus Henke, Rita Chung, Pieter Nel, and Sankalp Malhotra, "Notes for the AI Frontier - Insights from Hundreds of Use Cases," McKinsey&Company, April 2018. https://www.mckinsey.com/~/media/McKinsey/Featured%20Insights/Artificial%20Intelligence/Notes%20from%20the%20AI%20frontier%20Applications%20and%20value%20of%20deep%20learning/MGI_Notes-from-AI-Frontier_Discussion-paper.ashx, pg. 18.

next five years, 5G mobile technology is forecast to account for as many as 1.2 billion connections by 2025, covering one-third of the world's population.[55] 5G is expected to contribute to a 21% rise in global electricity consumption by 2030 from the production and operation of ICT while in just five years, data traffic will triple from 26.6 TB per second in 2016.[56]

Timeframe: <5 years |Volumes changed: data | Size of Impact: medium | Connectivity Levers: efficiency

4. *Blockchain/Distributed Ledger Tech (DLT)*

Blockchain is a decentralized form of exchange that is permanent and transparent between participating parties.[57] Instead of a central authority confirming transactions, blockchains like bitcoin rely on "miners" who use specialized computers to solve computing problems and verify each transaction. Blockchain reduces the need for intermediaries in the logistics sector who were previously required to act as trusted third parties to verify, record and coordinate transactions. Blockchain could boost global trade by $1.1 trillion by 2025 in new trading volume resulting by removing barriers through DLT.[58] Blockchain is expected to produce large amounts of data—from 0.1 to 1.9 billion terabytes projected by 2030—and unless verification processes change as planned, it will continue to consume huge amounts of energy (one projection estimates that yearly energy consumption in 2030 by miners alone could exceed today's worldwide energy supply by 14%).[59]

Timeframe: 5 to 10 years | Volumes changed: trade, data| Size of Impact: medium | Connectivity Levers: efficiency, sustainability

5. *Unmanned Aerial Vehicles (UAVs)*

Among other uses, UAVs can function as high altitude pseudo-satellites (HAPS) for internet access. HAPS are non-rigid airships, drones or balloons that hover or circulate currently around 15-30 km in the stratosphere, have lower transmission delay (latency) but also lower signal cover (footprint) than other technologies for internet access.[60] Current prototypes have provided 3G level access across a span of nearly 1,000 km using energy efficient methods.[61] UAVs can extend internet activity to remote areas where it may not be economically feasible to lay fiber optic cables while satellite access remains prohibitively expensive. As the drone

[55] GSM Association, "Charting the Course to 5G," accessed October 18, 2018. https://www.gsma.com/futurenetworks/technology/understanding-5g/5g-innovation/.

[56] Janine Morley, Kelly Widdicks and Mike Hazas, "Digitalisation, energy and data demand: The impact of Internet traffic on overall and peak electricity consumption", *Energy Research and Social Science,* Vol. 38, 2018, pg. 130. https://www.sciencedirect.com/science/article/pii/S2214629618301051

[57] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 20.

[58] World Economic Forum, and Bain & Company, "Trade Tech – A New Age for Trade and Supply Chain Finance," accessed October 27, 2018. http://www3.weforum.org/docs/White_Paper_Trade_Tech_report_2018.pdf.

[59] Markus Demary and Vera Demary, "Blockchain: Down to Earth", German Economic Institute, January 7, 2017, https://www.iwkoeln.de/en/studies/iw-kurzberichte/beitrag/markus-demary-vera-demary-blockchain-down-to-earth-317252.html.

[60] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 20.

[61] Jane's Military & Security Assessments Intelligence Centre, "High-Flying Bird: Zephyr Remains in the Vanguard of Solar-Powered Flight" accessed October 18, 2018. https://www.janes.com/images/assets/459/72459/High-flying_bird_Zephyr_remains_in_the_vanguard_of_solar-powered_flight.pdf, pg. 5
Maguire, Yael, "High Altitude Connectivity: The Next Chapter," accessed October 18, 2018. https://code.fb.com/connectivity/high-altitude-connectivity-the-next-chapter/.
Westgarth, Alastair, "Helping Out in Peru," May 17, 2017. https://medium.com/loon-for-all/helping-out-in-peru-9e5a84839fd2.

industry grows and the technology becomes cheaper, this solution may become viable by 2020.

Timeframe: <5 years | Volumes changed: data | Size of Impact: small | Connectivity Levers: inclusiveness

Production

6. Power storage

Power storage includes batteries, hydrogen energy or lithium ion cells that store energy for later use. When used with renewable energy like solar and wind, power storage improves energy security, increases grid stability and expands access to electricity. Hastened by the commercialization of electric vehicles and the rapid growth of renewables since 2010, manufacturers are racing to develop the technology to mitigate the intermittence of variable renewable energy through better storage systems. Lithium-ion batteries may remain the dominant power source for storage units until 2030 but new technologies are likely to enter the market after 2025.[62] By 2030, demand for lithium-ion storage is projected to rise to 1,784 gigawatt hours from a current level of about 100 gigawatts hours.[63] Consequently, current world exports of oil and coal are likely to continue to decline—volumes had already fallen by 10% over 2006 to 2016, while components for storage options will grow.[64]

Timeframe: 5 to 10 years | Volumes changed: energy | Size of Impact: high | Connectivity Levers: sustainability, efficiency, inclusiveness

7. Smart Grids

The electricity grid is a network connecting the end user to distribution and transmission. Smart grids use IoT, big data analytics and machine learning to optimize use of energy. Businesses and households could track, and even generate their own electricity and add this to the grid. Smart grids are likely to reduce energy usage, improve balancing energy supply and demand and result in greater efficiency.[65] Strong growth in the use of smart grids is foreseen by 2025.[66]

Timeframe: 5 to 10 years | Volumes changed: energy, data | Size of Impact: medium | Connectivity Levers: sustainability, scale economy, efficiency, inclusiveness

8. Ultra-High-Voltage-Direct-Current (UHVDC) Transmission Lines

UHVDC are high voltage transmission technologies that can carry electricity generated over longer distances, with potentially greater efficiency and at lower cost than existing technology. The ability to generate renewable energy, store it and transmit electricity at great distances will change the economics of the distribution of power. Around 250 gigawatts of interconnectors and high-voltage transmission links are installed globally; this is expected to increase by one-third before 2020, with usage expected to accelerate further by 2030.[67] UHVDC connectors also allow other energy sources like coal to be transmitted as electricity, at

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[62] Reed Landberg and Anna Hirtenstein, "Coal is Being Squeezed Out of Power by Cheap Renewables", *Bloomberg*, June 21, 2018, https://www.bloomberg.com/news/articles/2018-06-19/coal-is-being-squeezed-out-of-power-industry-by-cheap-renewables.

[63] Anna Hirtenstein, "The Battery Boom Could End up Burning Some Investors", *Blooomberg.* August 13, 2018. https://www.bloomberg.com/news/articles/2018-08-13/battery-technology-stranded-asset-debate-green-energy-revolution.

[64] World Trade Organisation (WTO), *World Trade Statistical Review 2017,* Geneva: WTO. https://www.wto.org/english/res_e/statis_e/wts2017_e/WTO_Chapter_03_e.pdf.

[65] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 18.

[66] International Energy Agency, "Smart Grids: Tracking Clean Energy Process", 2018. https://www.iea.org/tcep/energyintegration/smartgrids/

[67] International Energy Agency, *Large-scale Electricity Interconnection: Technology and prospects for cross-regional networks,* Paris: IEA, 2016, pg. 4. https://www.iea.org/publications/freepublications/publication/Interconnection.pdf

the source, rather than transported physically.[68]

Timeframe: 5 to 10 years | Volumes changed: energy, trade (-)| Size of Impact: high | Connectivity Levers: scale economy, sustainability, efficiency

9. 3D Printing

3D printing, also known as additive manufacturing, produces objects through a simple process of layering in contrast with traditional (subtractive) manufacturing, which creates parts out of raw materials.[69]By 2020, the 3D printing market is projected to be worth US$17.2 billion, with 15 to 20% growth in the aerospace (including defense) and automotive sectors, and as much as 30-35% growth in the energy sector.[70]The 3D printing market is estimated to grow to US$550 billion by 2025, and regional logistics may begin to rise with "re-shoring" or "near-shoring".[71]

Between 4.6 and 14.9% of global trade flows may be affected through efficiency gains and labor cost elimination as well as a shift in shipping.[72]Some estimate world trade may decline by as much as 38%, but not until 2040.[73] 3D printing is attractive for products that are not prone to large returns to scale. Energy savings of 5 to 27% of global demand are projected over a longer period; some projections indicate by 2050.[74]

Timeframe: 5 to 10 years | Volumes changed: trade (-), energy (-)| Size of Impact: medium| Connectivity Levers: scale economy, efficiency, sustainability

10. Autonomous Vehicles

Autonomous Vehicle (AV) technology ranges from the ones that enable a vehicle to assist and makes the decision for a human driver – crash warning systems, adaptive cruise control, and self-parking technology - to a vehicle that requires no driver at all.[75]

The use of AV technology for self-driving trucks may drastically disrupt the current landscape of the logistics and trade sectors. Not only can it reduce costs associated with traffic congestion, improve delivery times, increase overall efficiency, it can also reduce the frequency of crashes and fatalities associated with human errors.

By one estimate, driverless freight can save up to 40 % of operation costs per kilometer.[76]Labor currently accounts for an estimated 35 to 45 % of operating costs of road freight in Europe Vehicles, while AV can operate 24/7 without requiring rest time. More broadly AV vehicles may save

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[68]*The Economist,* "Rise of the Super Grid", January 14, 2017, https://www.economist.com/science-and-technology/2017/01/14/electricity-now-flows-across-continents-courtesy-of-direct-current

[69]United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 13.

[70]*Ibid*., pg. 14.

[71] Deutsche Post DHL Group, "2018/2019 Logistics Trend Radar," accessed October 12, 2018. http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/trendradar.html#.W2QjBjKFM2w, pg. 36.

[72]Hallward-Driemeier, Mary C.; Nayyar, Gaurav. 2017. *Trouble in the making? : the future of manufacturing-led development (English)*. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/720691510129384377/Trouble-in-the-making-the-future-of-manufacturing-led-development, pg. 137

[73]ING, "3D Printing: A Threat to Global Trade," ING, 8. https://www.ing.nl/media/ING_EBZ_3d-printing_tcm162-131996.pdf, pg. 8.

[74]Leendert Verhoef et. al. "The Effect of Additive Manufacturing on Global Energy Demand: An Assessment Using a Bottom Up Approach", *Energy Policy,* Vol. 112, January 2018, pg. 349-360. https://www.sciencedirect.com/science/article/pii/S0301421517306997.

[75] James M. Anderson, Nidhi Kalra, Karlyn D. Stanley, Paul Sorensen, "Autonomous Vehicle Technology", Santa Monica, California: RAND Corporation, 2016.

[76] DHL Trend Research, "Self-Driving Vehicles in Logistics", pg. 4. https://discover.dhl.com/content/dam/dhl/downloads/interim/full/dhl-self-driving-vehicles.pdf.

freight companies as much as 30 percent in driver costs by 2025.[77]

This would address in part the projected shortage in truck drivers available and willing to meet labor demand by 2030 under current working conditions.[78]If AV vehicles are broadly adopted, they would generate an estimated 4TB of data a day.[79]
Timeframe: 10 to 15 years | Volumes changed: trade, data. | Size of Impact: high| Connectivity Levers: efficiency, scale economy, sustainability, inclusiveness

Non-tech Disrupters

Policy/regulatory

11. Infrastructure Mega-Financing

Mega-financing for infrastructure is expected to carve open new markets and expand existing networks, thereby improving global and corridor inter-connectivity within the next decade. New financing solutions have emerged over the past five years, widening the pool of financing available for infrastructure projects such as new international financial institutions (IFI) like AIIB, new initiatives like the Belt and Road Initiative, the leveraging of IFI financing with private sector capital and a growing number of private equity funds focused on infrastructure financing. However, there is also concern over growing levels of public debt in some countries.

See "Disruptor in Focus" box for more details.
Timeframe: 5 to 10 years | Volumes changed: energy, trade, mobility, data| Size of Impact: high| Connectivity Levers: scale economy, efficiency, inclusiveness, sustainability

12. Border control tightening

Border controls restrict people's movement across international boundaries. These can affect how people, goods and services in multiple countries are connected to one another. The tightening of national borders in recent years is likely to limit access to opportunities and push for reshoring of production. The timeline is subject to the political, economic and election cycles.
Timeframe: <5 years |Volumes changed: mobility (-), trade (-)| Size of Impact: medium| Connectivity Levers: scale economy, inclusiveness, efficiency

13. Carbon Pricing

Carbon pricing is an instrument that captures the costs of greenhouse gas (GHG) emissions and ties them to their sources, usually in the form of a price on the carbon dioxide (CO_2) emitted. This creates a disincentive for emitting carbon. Currently, there are 25 cap and trade markets, mostly regional or sub-national, and carbon taxes are implemented at the national level in 26 countries, covering almost 15 percent of annual greenhouse gases (GHGs) emissions globally. Carbon pricing initiatives are

[77] Isabel von Kessel, "Autonomous Trucks Will Mean Big Savings for Freight Companies, July 11, 2017, *statista.com.* https://www.statista.com/chart/10224/self-driving-trucks/.

[78] International Transport Forum, *Managing the Transition to Driverless Road Freight Transport*, Paris: ITF, 2017, pg. 7.
[79] Brian Krzanich, "Data is the new oil in the future of automated driving", Intel.com, Nov. 15, 2016

expected to cover 20percent of global GHGs by 2020.[80]

Remarkable progress in renewable energy, led by faster-than-expected growth in solar power,[81] will help enable global decarbonization. Despite concerns, there is no evidence that carbon pricing will have a negative impact on trade competitiveness. The impact on trade can be managed through planning for decarbonization and leveraging technological advances. For instance, the International Maritime Organisation made an unprecedented announcement that it would reduce annual GHGs by at least 50% by 2050 compared to 2008 levels, and fully decarbonize through technological innovation, low/zero carbon energy use.[82]

Timeframe: < 5 years | Volumes changed: energy (-), trade (-), mobility (-)| Size of Impact: high | Connectivity Levers: sustainability, inclusiveness, efficiency

14. Decarbonization

Current world trade in oil was at 3.32 billion tons in 2017 and seaborne coal trade was at 1.14 billion tons in 2016. Even if global energy demand is rapidly increasing, long-term decarbonization policies can shrink the demand for coal and oil. Volumes already fell by 10% over 2006 to 2016.[83] New energy transmission technology will enable coal to be transmitted as electricity over long distances, from the source, rather than transported physically.[84]Some estimate energy-related shipping may decline by 50% for coal and 25% for oil by 2050.[85] This will limit the need for new investments for coal and oil transport infrastructure by sea or rail.

Timeframe: 10 to 15 years | Volumes changed: energy (-), trade (-) | Size of Impact: high| Connectivity Levers: sustainability

15. Cyber-vulnerability

As the logistics and trade sectors become more tightly integrated and reliant on Big Data analytics, IoT, and AI in their business models, their vulnerability to cyber-attacks increases, leading to heightened risk of disruption in businesses and global value chains. With increased digitalization across different sectors, cyber-vulnerability will be a paramount concern. The growth of the IoT, particularly in the energy sector, along with diversification and decentralization of using IoT devices, expands the "attack surface" vulnerable. By 2025, almost 90% of data will require security but less than 50% may be secured.[86]

As a result, cybersecurity – safeguarding data and intellectual property rights – is crucial to maintain global inter-connectivity. Given how the world is already closely intertwined online, governments are already working towards implementing policies and creating teams to counter cyber threats.

Timeframe: 0 to 10 years | Volumes changed: mobility (-), trade (-), energy (-), data (-)| Size of Impact: medium | Connectivity Levers: efficiency, sustainability

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[80] The World Bank, *State and Trends of Carbon Pricing 2018,* Washington DC: World Bank, 2018, pg. 19-20. https://openknowledge.worldbank.org/handle/10986/29687.

[81]International Energy Agency, "Solar Leads the Charge In Another Record Year for Renewables," accessed November 5, 2018. https://www.iea.org/publications/renewables2017/.

[82] International Maritime Organisation, "UN Body adopts climate change strategy for shipping", April 13, 2018. http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx.

[83]World Trade Organisation (WTO), *World Trade Statistical Review 2017,* Geneva: WTO. https://www.wto.org/english/res_e/statis_e/wts2017_e/WTO_Chapter_03_e.pdf.

[84]*The Economist,* "Rise of the Super Grid", January 14, 2017, https://www.economist.com/science-and-technology/2017/01/14/electricity-now-flows-across-continents-courtesy-of-direct-current.

[85]Maria Sharmina et. al., "Global Energy Scenarios and their Implications for Future Shipped Trade", *Marine Policy*, Issue No. 84, 2017, pg. 12.

[86] Reinsel, David, John Gantz, and John Rydning, "Data Age 2025: The Evolution of Data to Life-Critical," Seagate,accessed November 10, 2018. https://www.seagate.com/www-content/our-story/trends/files/Seagate-WP-DataAge2025-March-2017.pdf.

Social/business

16. Near-shoring/Re-shoring

Near-shoring or re-shoring is the opposite of the trend of off-shoring production across long global supply chains. Incentives such a high demand for speed of delivery, customization, reduction of lead times and cutting down on inventory costs will spur a growing level of goods production and parts manufacturing to be done on demand, on-site or near the end user, possibly within the next five years.[87]

Timeframe: <5 years | Volumes changed: trade (-)| Size of Impact: medium| Connectivity Levers: scale economy, sustainability, efficiency

17. Asset Sharing

With the combination of Big Data analytics, AI and the expansion of logistics and trade platforms across borders to serve new markets, new business models will transform existing services.[88]For example, the "uberization" of trucking, essentially the utilization of app-based technologies for freight consolidation, may disrupt the conventional business model of logistics companies, especially that of third-party logistics providers (3PLs). By increasing the loading of trucks on return trips, new platforms (like Cainiao) will lower costs and improve efficiency.

To address trust concerns and proper matching for different types of cargo, a rich ecosystem will need to develop, leveraging on some of the cross-border platforms already emerging in Asia. Asset sharing platforms may grow in the meantime to maximize efficiency as better information becomes available.

Timeframe: 5 to 10 years | Volumes changed: trade | Size of Impact: medium | Connectivity Levers: efficiency, scale economy, inclusiveness

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[87]Deutsche Post DHL Group, "2018/2019 Logistics Trend Radar," accessed October 12, 2018. http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/trendradar.html#.W2QjBjKFM2w, pg. 36.

[88]*Ibid*., pg. 28.

Disrupter in Focus: Infrastructure Financing

Infrastructure financing requirements until 2030 will run up to trillions of dollars. In 2017, the Asian Development Bank estimated that in Asia alone, developing countries will need to invest US$26 trillion from 2016 to 2030, or US$ 1.7 trillion per year, double of previous estimates, including the costs of climate mitigation and adaptation.[89] According to a recent OECD study, current spending on transport connectivity in developing countries needs to be more than doubled to meet the SDGs. Similarly, the European Union requires about 1.5 trillion Euros of investment in the Trans-European network for transport, from 2021 to 2030.[90]

To meet such needs, optimizing financing and funding schemes for new infrastructure will be a priority for governments, considering infrastructure sub-sector characteristics and limitations in public funding and contingency exposure. There are major differences across sub-sectors in terms of private sector capacity to come in, and in terms of public funding capacity to raise private and commercial financing to fill the financing gap[91]. Relative to investment size, telecommunications and the power sector have been most effective in attracting private capital owed to the direct monetization of the infrastructure services they provide. Similarly, on the transport side, infrastructure that leads to direct monetization, like airport and ports, or high-volume motorways, have been the most successful at attracting private capital. Assets that serve broader societal goals, like last mile connectivity, or those with limited tradition for direct payment, like access to a core road network, or those with low profitability, like many railway networks, have attracted fewer private investments, due to the lack of associated cash flow streams supporting rates of returns compatible with private financing and commercial operations.

Financing for infrastructure from new initiatives and development banks is expected to help fill part of these financing needs, carve open new markets and expand existing networks. Connectivity initiatives such as the Belt and Road Initiative (BRI) will support infrastructure financing for an estimated US$ 1 trillion or more, mainly financed by the Chinese development banks, the US$ 40 billion Silk Road Fund, and two of the large state-owned commercial banks.[92] New development Banks like AIIB and NDB have already started to supplement the role of earlier multilateral development banks. But, since collectively and together with traditional IFIs their financing is still a small percentage of financing needs required, their impact will be magnified wherever they succeed in crowding private capital from long-term investment groups like pension plan and insurance, as pursued by the World Bank Group and other IFIs and recommended by the OECD.

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[89] Sungsup Ra and Zhigang Lli, "Closing the Financing Gap in Asian Infrastructure", *ADB South Asia Working Paper Series* No. 57., Manila: Asian Development Bank, June 2018, pg. 2. https://www.adb.org/sites/default/files/publication/431261/swp-057-financing-gap-asian-infrastructure.pdf.

[90] High Representative of the European Union for Foreign Affairs and Security Policy, "Connecting Europe and Asia—Building blocks for an EU Strategy", European Commission, Brussels, September 19, 2018.

[91] *2018 Funding and Financing Infrastructure*. DC: World Bank http://documents.worldbank.org/curated/en/176101530040441739/pdf/WPS8496.pdf

[92] *2018 OECD Business and Financial Outlook*. Paris: OECD. http://www.oecd.org/investment/oecd-business-and-finance-outlook-26172577.htm.

The infrastructure challenge will however only be addressed by unlocking private capital and facilitating its flows towards markets private investors have been less active in. The private sector invests about 3.5 times in transport infrastructure as much as IFIs, with a focus on Latin America, Europe and upper middle-income countries, while IFIs focus on Asia, Africa and low-income countries[93]. IFIs, as mandated by the G20, are developing mechanisms to facilitate the flow of private finance into those underserved markets by improving the investment climate, increasing revenue generation, de-risking projects and boosting productive capacity, especially in lower income countries. For example, the combined public and private financing arms of the World Bank Group institutions are expected to reach an annual financing capacity of nearly $100 billion between 2019 and 2030, and leverage those resources to foster private capital investments.[94]

In parallel, the challenge of debt sustainability related to such investments needs to be addressed. While debt financing is essential for large infrastructure development, the relevance of such investments compared to other government priorities needs a thorough assessment. Past studies of overland corridor programs stress the importance of planning in the prioritization and sequencing of projects to maximize the benefits of such program. The processes behind the establishment and maintenance of connectivity must be designed and planned in advance, involving intense efforts to develop joint action frames, governance structures, institution-building and policy frameworks[95], leading to the development of economic corridors.[96] Such investments should also be sustainable in all aspects. Borrowers without enough economic growth and revenue to service such debt may be forced to reduce domestic infrastructure spending, curtail spending on social services, and borrow additional funds just to meet debt servicing needs.[97] As International Monetary Fund Managing Director Christine Lagarde observed in Beijing, any large-scale spending is bedeviled by risks of potential project failure and the misuse of funds. In countries where public debt is already high, careful prioritization and management of financing terms are critical to protect both the lending agency and its partner,[98] to lessen vulnerability to debt distress.[99]

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[93]OECD, *Enhancing Connectivity through Transport Infrastructure: The Role of Official Development Finance and Private Investment*, Paris: OECD, 2018. https://www.oecd-ilibrary.org/development/enhancing-connectivity-through-transport-infrastructure_9789264304505-en.

[94] World Bank Group, "Financing for Development at the World Bank Group", 2018. http://pubdocs.worldbank.org/en/822151531513670691/FinancingforDevelopmentattheWBGBrochureJuly2018Edition-Updated-July-22-2018-reduce-file-size-final.pdf.

[95] Charles Kunaka, Xingjian Liu and Ben Derudder, "Connectivity Along Overland Corridors of the Belt and Road Initiative", Discussion Paper MTI Global Practice No.6, Washington DC, The World Bank, October 2018. http://documents.worldbank.org/curated/en/264651538637972468/pdf/130490-MTI-Discussion-Paper-6-Final.pdf, pg. 49.

[96]Asian Development Bank; UKAID; JICA; World Bank Group. 2018. The WEB of Transport Corridors in South Asia. Washington, DC: World Bank. http://hdl.handle.net/10986/28882

[97] John Hurley, Scott Morris and Gailyn Portelance, "Examining the Debt Implications of the Belt and Road Initiative from a Policy Perspective", Washington, DC: Center for Global Development, 2018, pg. 15-16. https://www.cgdev.org/sites/default/files/examining-debt-implications-belt-and-road-initiative-policy-perspective.pdf.

[98] Christine Lagarde, "Belt and Road Initiative: Strategies to Deliver in the Next Phase", April 12, 2018, https://www.imf.org/en/News/Articles/2018/04/11/sp041218-belt-and-road-initiative-strategies-to-deliver-in-the-next-phase.

[99] John Hurley, Scott Morris and Gailyn Portelance, "Examining the Debt Implications of the Belt and Road Initiative from a Policy Perspective", Washington, DC: Center for Global Development, 2018, pg. 15-16. https://www.cgdev.org/sites/default/files/examining-debt-implications-belt-and-road-initiative-policy-perspective.pdf.

The Frictionless Economic Corridor

By 2030, the International Transport Forum (ITF) of the Organisation for Economic Co-operation and Development estimates that global freight volumes will grow by 70percent compared to 2015 and there will be an additional 1.2 billion cars on the road—double today's total.[100] Regional transportation connectivity is vital to supporting the integration of new markets and promoting interoperability in transport systems, reducing transportation costs and catalyzing economic growth overall.[101] For some regions, improving the regional integration of the transport sector could lead to GDP increases of 2 to 3 percent per year.[102] Consequently, policy frameworks to foster trade and the transport sector's regional integration require improvements in regional infrastructure connectivity of ports, railways and roads.[103]

With policy frameworks and investment in place, economic corridors can reap the benefits that technological advances promise. Autonomous trucks, as well as cars and ships are on the horizon. In the next 10 to 15 years, autonomous trucks might be the first to cross the threshold into the reality of cross-border trade. The prerequisite technology includes 5G or the next generation of mobile internet, which will allow AVs to communicate with each other and the road, and

Case Study

KEY MESSAGES

On volumes

- Without drivers, autonomous trucks can increase throughput and reduce delays, lowering operational costs by up to 40% and reducing labor costs by as much as 30% by 2030—with a likely positive impact on trade throughput
- If broadly adopted, AV vehicles will increase data usage through vehicle-to-vehicle and vehicle-to-infrastructure communication
- Trucks that are autonomous and electric can provide double benefits: diminishing the use of oil and reducing carbon emissions
- AV efficiency can reduce the carbon footprint from trucking by up to 60%

On connectivity

- Autonomous trucks in cross-border regional trade and through economic corridors can raise economic competitiveness
- Regional integration can reduce transportation costs for cross-border trade, catalyze growth and raise GDP by 2 to 3 percent, per year

Planning for cross-border infrastructure

- Earmark spectrum for IoT networks and vehicular radar communications
- Ready the physical infrastructure for connectivity requirements
- Prepare the regulatory framework
- Facilitate trade with "Single Window" processes
- Harmonize common vehicle standards and operational rules
- Address labor and other forms of economic dislocation

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[100] Sustainable Mobility for All, "Global Mobility Report 2017," accessed November 9, 2018. http://sum4all.org/publications/global-mobility-report-2017.
[101] UNECE, "Promoting Transport Connectivity and Regional Integration" (slide deck). https://www.unece.org/fileadmin/DAM/trans/doc/2017/TEM/2017/European_Bank_for_Reconstruction_and_Development__EBRD_.pdf.
[102] International Transport Forum, "Looking Towards 2019: Transport Connectivity for Regional Integration". https://2018.itf-oecd.org/2019-connectivity.
[103] United Nations Economic and Social Commission for Asia and the Pacific, "Review of Developments in Transport in Asia and the Pacific 2017," accessed October 30, 2018. https://www.unescap.org/sites/default/files/publications/Review2017_Hires_21Dec2017.pdf.

sensors, particularly those that provide telemetry to the AVs. There is reasonable expectation that 5G internet and other requisites will be available within the next five years.

Autonomous trucks would be well suited for long distance trips on key corridors. In the future, one can anticipate self-driving trucks leaving an export zone in one country, traveling along a major highway to another country, exchanging data at borders electronically with automated processing through a single window for authorized traders and vehicles, and reaching a final inland import zone in another country, from which goods will be dispatched to the local market.

However, uncertainties until 2030 remain regarding (1) public acceptance of AVs on the road and (2) the extent to which regional groups will harmonize and facilitate the use of AVs in cross-border trade. This case study offers a scenario of "frictionless" economic corridors through which AVs carry freight smoothly, and policy recommendations for better infrastructure connectivity.

Autonomous Vehicles: A Closer Look

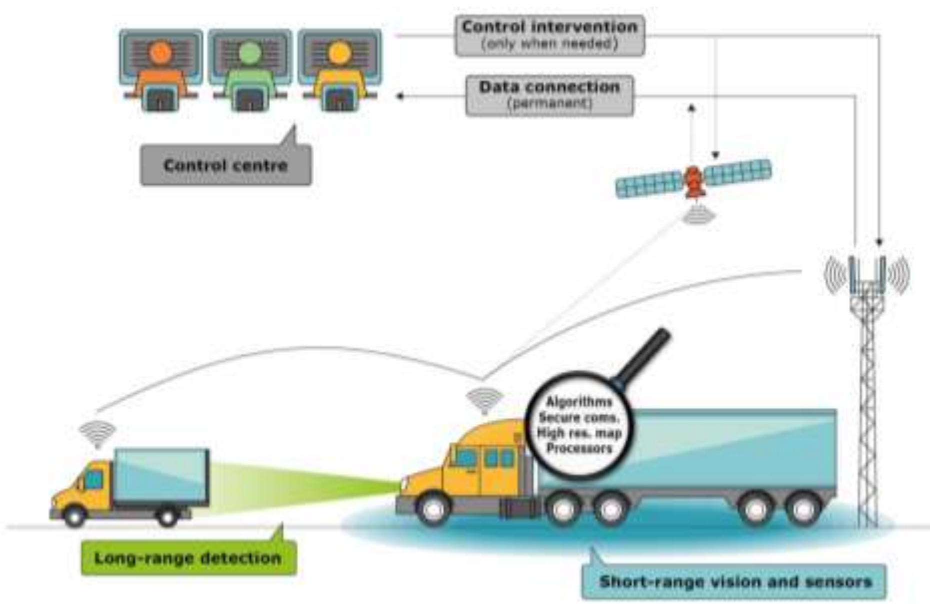

Figure 11: A Driverless Truck Operating Environment (Example with Optional Control Center)
Source: International Transport Forum

AVs can fundamentally reshape the future of transportation. AVs span a technological continuum, ranging from the ones that enable a vehicle to assist and make decisions for a human driver – crash warning systems, adaptive cruise control, and self-parking technology - to a vehicle that requires no driver at all. ITF projects that autonomous trucks can be brought to market as early as 2021 or, if treated very cautiously by authorities, by 2030 or even later.[104]

In Europe, more than a dozen self-driving trucks made by six of Europe's largest car manufacturers traveled from various factory locations including Sweden and South Germany to Rotterdam harbor, completing the first cross-border travel of a "truck platooning" in 2016.[105]The wave of automation has reached the maritime transportation as well, with the Yara Birkeland, the world's first crewless, autonomously operated ship developed by Yara International ASA and Kongsberg Gruppen ASA.[106]Rolls-Royce has mounted a joint industry project in Finland called Advanced Autonomous Waterborne Applications (AAWA). The participants hope to create the technology for a remotely controlled or fully autonomous ship that will operate in coastal waters before the end of the decade.[107]

The development of a number of informational disrupters within the next five years will enable AV development. This includes sensors in the vehicles or in the road infrastructure that will communicate with the vehicles and enable vehicle-to-vehicle communication, and provide the telemetry needed for the vehicles to respond to changes in the environment. Sensor data can then be analyzed for quick response, but the ability of AVs to become safer will depend on AI improvements. Driverless vehicles will require an enormous amount of data to be shared, so having a high bandwidth and fast wireless communication via the next generation based on faster 5G technology will be essential.[108]

Autonomous Vehicles and Freight Transport

In relation to logistics and trade, AV technology can drastically change the current landscape of line-haul operations and necessitate a re-evaluation of trade throughput. The logistics industry currently favors the hub-and-spoke model of aggregating parcels in central locations before sending them out to delivery depots, as it reduces fixed costs including the labor costs of drivers—as high as 45% in high income countries.

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[104]International Transport Forum, "Managing the Transition Towards Driverless Road Freight Transport," accessed October 27, 2018. https://www.itf-oecd.org/sites/default/files/docs/managing-transition-driverless-road-freight-transport.pdf, pg. 13.
[105]AFP, "Convoy of self-driving trucks completes first European cross-border trip", *The Guardian,* April 7, 2016. https://www.theguardian.com/technology/2016/apr/07/convoy-self-driving-trucks-completes-first-european-cross-border-trip.
[106] Costas Paris, "Norway Takes Lead in Race to Build Autonomous Cargo Ships", *Wall Street Journal.* July 22, 2017. https://www.wsj.com/articles/norway-takes-lead-in-race-to-build-autonomous-cargo-ships-1500721202.
[107] Matt Reynolds, "Rolls-Royce unveils concept fleet of self-driving drone ships-and it could launch by 2020", *Wired,* June 27, 2016. https://www.wired.co.uk/article/rolls-royce-autonomous-cargo-ships.
[108]Fallah, Saber, "We're Not Ready for Driverless Cars," April 30, 2018. https://www.weforum.org/agenda/2018/04/driverless-cars-are-forcing-cities-to-become-smart.

Autonomous trucks could potentially save freight companies an estimated 30% of these costs by 2025 while its continuous driving virtually without rest could save up to 40% of operational costs.[109]

By reducing the labor part in truck operations, AV technology can facilitate point-to-point connection and enable a continuous flow model, although this may be more applicable to domestic commerce initially than international trade. Parcel players may opt for smaller trucks on a point-to-point connection to enhance service delivery. This may significantly narrow the current cost gap between large and small trucks and save on transport time (i.e., transshipment). Overall, AVs will result in greater convenience for customers with later drop-off times and shorter delivery of parcels. BCG estimates that AVs can reduce line-haul costs by more than half. (See Figure 12 below). In the longer term autonomous truck could start plying international corridors, cutting down transport cost and stimulating regional integration.

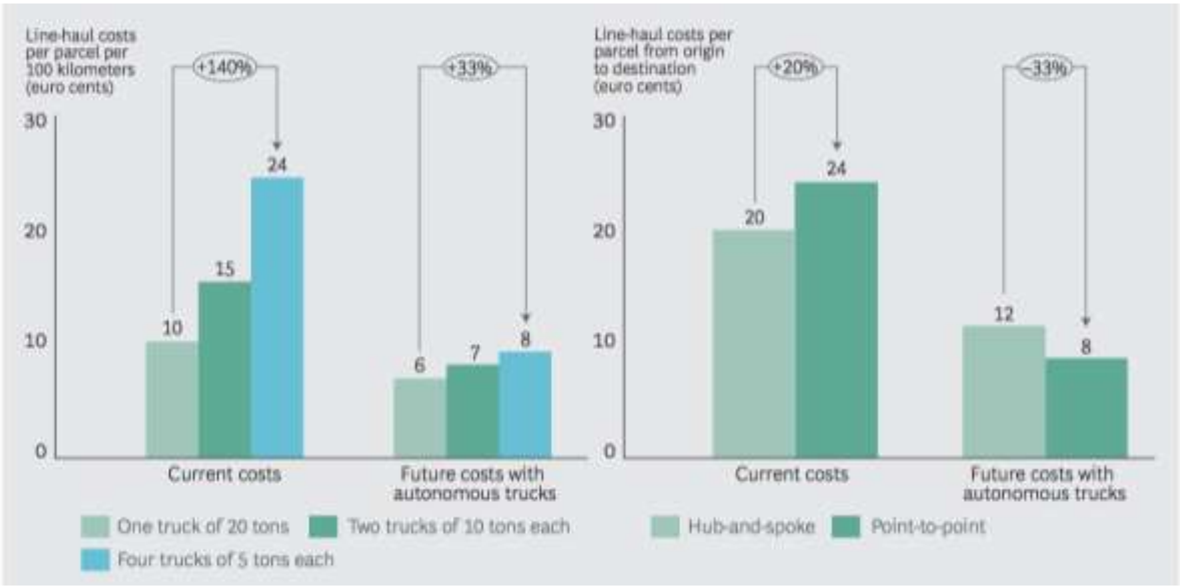

Figure 12: Autonomous Trucks Would Make Line Hauls More Effective
Source: Boston Consulting Group (BCG)

[109]DHL Trend Research, "Self-Driving Vehicles in Logistics", pg. 4. https://discover.dhl.com/content/dam/dhl/downloads/interim/full/dhl-self-driving-vehicles.pdf.

Under favorable circumstances, autonomous trucks have other potential advantages for connectivity infrastructure. Road safety and reduction in vehicle-related accidents and fatalities will be improved through reduced human error. Existing road infrastructure throughput will increase as a result of more-efficient vehicle operation, reduced delays from crashes, improved traffic flows from cars, and truck platooning driving at consistent speed. Autonomous systems can set higher average speeds and intelligently avoid busy routes through vehicle-to-vehicle communication. AV efficiency can also contribute to sustainable transportation and reduce the carbon footprint, in some estimates by as much as 60%.[110]Autonomous trucks on highways are likely to move to large scale commercialization earlier than in cities, considering the lower level of complexity highways entail.[111]

Several companies are hitching sustainability aims on to self-driving vehicles. For instance, Tesla is working on a fully autonomous and fully electric truck. For successful commercialization, reducing the weight of the battery will be a major requirement as the current weight of batteries reduces the payload of such vehicles. According to the International Renewable Energy Agency (IRENA), lithium ion batteries for electric vehicles and other uses has reached a new phase of maturation, making batteries more compact, lighter, durable and quickly rechargeable—competitive with internal combustion engines by 2030 or slightly earlier.[112]Others are exploring solutions such as using hydrogen fuel cell power or cables over the freeway to deliver electricity on the move.[113]

Autonomous trucking seemingly responds to the shortage of truckers in countries like the US and Canada as fewer people are willing to pursue such a difficult lifestyle.[114]Despite driver scarcity in higher income countries, labor displacement will pose a challenge to the adoption of autonomous trucks and other vehicles. It is likely that driverless trucks will reduce demand for drivers quicker than labor shortages develop: the ITF has estimated that over 2 million truck drivers across the US and Europe could be directly displaced if autonomous trucks are deployed quickly by 2030.[115]Security risks for hacking and theft likewise will need to be guarded against.

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[110]Bertoncello, Michele, and Dominik Wee, "Ten Ways Autonomous Driving Could Redefine the Automotive World," June 2015. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/ten-ways-autonomous-driving-could-redefine-the-automotive-world.

[111]Stewart, Jack, "As Uber Gives Up on Self-Driving Trucks, Another Startup Jumps In," July 8, 2018. https://www.wired.com/story/kodiak-self-driving-semi-trucks/.

[112] International Renewable Energy Agency. "Electric Vehicles - Technology Brief," International Renewable Energy Agency, February 2017. http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/IRENA_Electric_Vehicles_2017.pdf, pg. 10.

[113]Stewart, Jack, "Tesla's Electric Truck Is Coming - And So Are Everyone Else's," November 15, 2017. https://www.wired.com/story/teslas-electric-truck-is-comingand-so-are-everyone-elses/.

[114]Davies, Alex. "Self-Driving Trucks Are Now Delivering Refrigerators," November 13, 2017. https://www.wired.com/story/embark-self-driving-truck-deliveries/.

[115]International Transport Forum, "Managing the Transition Towards Driverless Road Freight Transport," accessed October 27, 2018. https://www.itf-oecd.org/sites/default/files/docs/managing-transition-driverless-road-freight-transport.pdf, pg. 7.

What If Driverless Trucks Could Ply Regional Corridors?

Scenario 1:

The gains of long-haul, driverless transportation would be maximized if autonomous trucks are allowed to expand outside of the current geo-fenced testing areas and cross borders. Such a measure would dramatically increase the efficiency of transporting goods through a regional economic corridor, especially if coupled with "national single window" coordination and other trade facilitation reforms to cut down transaction times.[116] An early mover in this direction is the European Union (EU), a free trade area in which 28 member states have agreed to designate digital cross-border corridors, where vehicles can physically move across borders for digital technology testing and demonstration—including automated driving.[117] The EU is already preparing at least 10 cross-border corridors with 5G connections and hundreds of kilometers of motorways for autonomous vehicles.[118] Other trials in countries like the US, where the major AV companies and start-ups are developing the technology, and Singapore, are expected to be scaled up.

Scenario 2:

In an alternative scenario in which AV is commercialized but where countries are not well integrated into a region, autonomous trucks may be in use in specially negotiated areas. Therefore, transport of goods using autonomous trucks would traverse only one or two border crossing points along designated economic corridors. Some corridors may become more competitive through such efficiency improvements and enhanced trade facilitation, generating scale economies.

Policy Recommendations

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[116] Charles Kunaka and Robin Carruthers, 2014, "Trade and Transport Corridor Management Toolkit", http://documents.worldbank.org/curated/en/719971468325781473/pdf/879490PUB0Trad00Box385214B00PUBLIC0.pdf, pg.157.

[117] European Commission, "Connected and Automated Mobility in Europe," accessed October 18, 2018. https://ec.europa.eu/digital-single-market/en/connected-and-automated-mobility-europe.

[118] European Commission, "New 5G cross-border corridors for connected and automated mobility in the Baltics will allow testing of autonomous vehicles", September 26, 2018, https://ec.europa.eu/digital-single-market/en/news/new-5g-cross-border-corridors-connected-and-automated-mobility-baltics-will-allow-testing. European Commission, "Cross-border corridors for Connected and Automated Mobility", May 7, 2018. https://ec.europa.eu/digital-single-market/en/cross-border-corridors-connected-and-automated-mobility-cam.

AV technology is getting closer to maturity and commercial introduction, although for it may take at least one more decade for it to become mainstream. Autonomous trucks are nevertheless expected to be start being commercialized shortly. The following policy aspects will be relevant to governments and other stakeholders that are in regions or countries poised to adopt AV technology in the coming decade.

Earmark spectrum for IoT networks and vehicular radar communications

AVs need highly reliable and medium-long range connectivity, to stay connected with other vehicles (vehicle-to-vehicle, or V2V) and the infrastructure (vehicle-to-infrastructure, V2I). AVs require an underlying Internet-of-Things (IoT) network along the roads to support the networked software and sensors on the vehicle.[119] Connected vehicles require increased data flows from various radar applications including lane change warnings, blind spot detection, autonomous braking and pedestrian detection technology. Thus, an adequate level of spectrum for 5G or dedicated short-range communications (DSRC) needs to be reserved.[120]

Ready the physical infrastructure for connectivity requirements

The next generation 5G network, which is one of the potential IoT networks that would support AVs, requires dense links of small cells and small antennas. Designated space, in urban (rooftops, buildings, lampposts) and interurban areas (along highways), will be needed to set up such antennas, with a planning role for governments to ensure that physical infrastructure can accommodate such new network.

A potential strategy is to review and amend building codes to further facilitate deployment of communication infrastructure. This could open up the possibility of equipping outdoor facilities along the road such as road lamp posts, billboards and bus stops in preparation for the 5G deployment.

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[119] Daniel Alsén, Mark Patel, and Jason Shangkuan. 2017. Mckinsey&Company, ' The future of connectivity: Enabling the Internet of Things.' November. Accessed 19 December 2017. https://www.mckinsey.com/global-themes/internet-of-things/our-insights/the-future-of-connectivity-enabling-the-internet-of-things?cid=other-eml-alt-mip-mck-oth-1712.

Also, McKinsey (2017) 'Advanced driver-assistance systems: Challenges and opportunities ahead', accessed from https://www.mckinsey.com/industries/semiconductors/our-insights/advanced-driver-assistance-systems-challenges-and-opportunities-ahead.

[120] IEEE Standards Association, "Will Wireless Connections Between Autonomous Vehicles Make Them Safer?" *Futurism*, August 22, 2017. https://futurism.com/will-wireless-connections-between-autonomous-vehicles-make-them-safer.

Another consideration for infrastructure planning includes the possibility that autonomous trucks will also be electric, requiring adequate charging facilities.[121] Apart from batteries, some options currently being tested include overhead lines and inductive transfer of power using coils embedded in the road surface.

Prepare the regulatory framework

Just as in any new technology, regulations will play an important role in the emergence and development of AV technology. Staying ahead of the curve would help governments avoid a patchwork of conflicting regulatory requirements and promote social welfare. The ITF recommends that governments, industry and researchers continue testing on public roads and designated corridors so that various technologies are tested without committing to an individual company, standard or technology, early in the development process.[122]

Facilitate Trade with electronic "Single Window" Processes

National single windows refer to the coordinated exchange of information among national regulatory agencies to simplify the submission of all import, export and transit information through a sole electronic gateway.[123] Enabling regional single window systems and global standards hinge on the interoperability of trade facilitation.[124] According to the World Bank, global welfare would gain some $210 billion per year if transaction time at the borders would lessen, especially through electronic systems.[125]Allowing autonomous vehicles with proper authorized status to make border crossings can push broader border and transit management reforms.

Collaborate with neighboring countries for seamless cross-border mobility

Mobility, automated or not, has to work across borders, and AVs bring a new set of cross-border coordination issues. Difficulties include standardizing regulations across continents to enable self-driving convoys and designing systems facilitating communication between different trucks from different manufacturers. The ITF emphasizes that the harmonization of rules across countries is crucial for maximizing the gains from driverless truck technology. Common vehicle standards and operation rules would allow a smooth cross-border movement of autonomous trucks across a continent while test permits and *ad hoc* exemptions will be needed to facilitate harmonization rather than disarray.[126]

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[121]International Energy Agency, "The Future of Trucks: Implications for Energy and the Environment," accessed October 28, 2018. https://www.iea.org/publications/freepublications/publication/TheFutureofTrucksImplicationsforEnergyandtheEnvironment.pdf., pg. 94- 95.

[122] International Transport Forum, *Managing the Transition to Driverless Road Freight Transport*, Paris: ITF, 2017, pg. 13.

[123] Charles Kunaka and Robin Carruthers, 2014, "Trade and Transport Corridor Management Toolkit", http://documents.worldbank.org/curated/en/719971468325781473/pdf/879490PUB0Trad00Box385214B00PUBLIC0.pdf, pg. 179.

[124] APEC Policy Support Unit, *Study on Single Window Systems' International Interoperability: Key Issues for Its Implementation*, Singapore: APEC, 2018, pg. 9-10.

[125] World Bank Doing Business 2017 Report, Washington, DC: The World Bank, 2017, pg. 36-37.

[126] International Transport Forum, *Managing the Transition to Driverless Road Freight Transport*, Paris: ITF, 2017, pg. 8.

Address labor and other economic dislocation as transit areas are bypassed

Governments could maintain a dialogue with representatives from communities, unions and industries that will be potentially dislocated, to design ways of mitigating potential economic dislocation. The ITF advises that governments considering AV must now prepare for potential negative social impacts such as job losses and long-term unemployment—even in the US and Europe where there is currently a shortage in drivers. Support systems will need to brace for a potential high speed and large scale of dislocation, if driverless vehicles are adopted quickly.[127]

Anticipate Future Developments

Countries that decide against allowing autonomous vehicles should continue to work with their neighboring countries on trade facilitation, including through enhancement of their "national single window". These policies are essential to improve transport efficiency even if autonomous vehicle technology fails to be mainstreamed by 2030.

[127] *Ibid.*, pg. 7.

Electricity 2.0

Secure and affordable electricity is integral to poverty reduction and economic growth. The International Energy Agency (IEA) projects that the global demand for electricity will accelerate (See Figure 13)and make up 40% of final energy consumption by 2040, driven by industrial use, rising incomes andelectric cars.

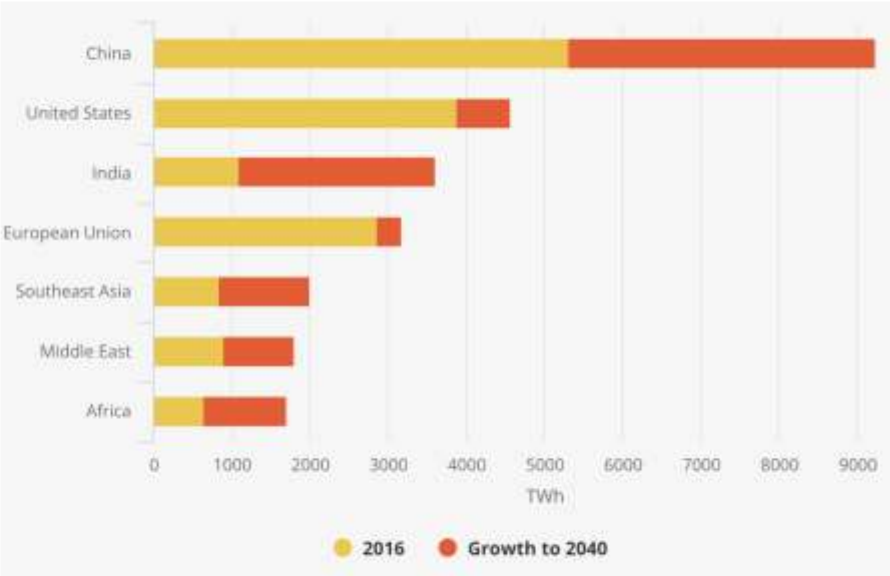

Figure 13: Electricity Demand by Selected Region
Source: International Energy Agency, World Energy Outlook 2017

KEY MESSAGES

On volumes

- Rapidly falling costs of solar and wind power generation have already begun to disrupt the energy sector and renewables may grow from 25 percent in the global power generation in 2017 to as much as 45 percent in 2030 to 60 percent in by 2050
- Decarbonization will reduce the role of fossil fuels, and combined with transmission technology improvements, could lead to a decline in energy related shipping by as much as 50% for coal and 25% for oil by 2050
- Past trends failed to predict sudden rise of renewables

On connectivity

- Smart grids, power storage and long-distance transmission will help balance energy demand and supply and manage distribution more efficiently.
- The ability to generate renewable energy, store it and transmit electricity at great distances will change the economics of the power.
- Universal access to electricity is achievable by 2030 with renewables and mini-grid investments
- Until 2050, IRENA estimates at least US$ 24.6 trillion is needed to decarbonize power generation, with potential stranded assets at US$1 to 1.4 trillion

Planning for cross-border infrastructure

- Set targets for access to electricity
- Develop an integrated regional market for energy trading
- Identify stranded asset risks and plan for an orderly transition
- Address environmental and social concerns
- Enhance cybersecurity

The IEA reports that approximately 1.1 billion people or 14% of the global population continue to live without access to electricity. Improvements in the past two decades have been made primarily through the expansion of central electricity grids and the use of fossil fuel. Since 2012, however, access to energy has accelerated to 100 million people gaining access a year with over a third of access coming from renewable sources of electricity.[128] The transition to a low carbon energy future underpins the Paris Agreement on climate change and the Sustainable Development Goals (SDGs) for 2030. The recent IPCC report on the more ambitious 1.5°C target in the Paris Agreement has underscored the urgency of decarbonization. Improving global energy connectivity is essential in driving this transition forward.

Renewable energy requires different infrastructure than fossil fuels, posing immense challenges for aging and outdated centralized electricity grid facilities in both developing and developed countries. The IEA estimates that US$334 billion in cumulative investment would be needed to reduce the proportion of the population without access to electricity to 8% by 2030, of which 80% will be in rural areas; for *universal* access by 2030, another $391 billion would be required.[129] The pathway to universal access to electricity by 2030 would require a massive expansion of solar photovoltaic (PV) use. (See Figure 14)

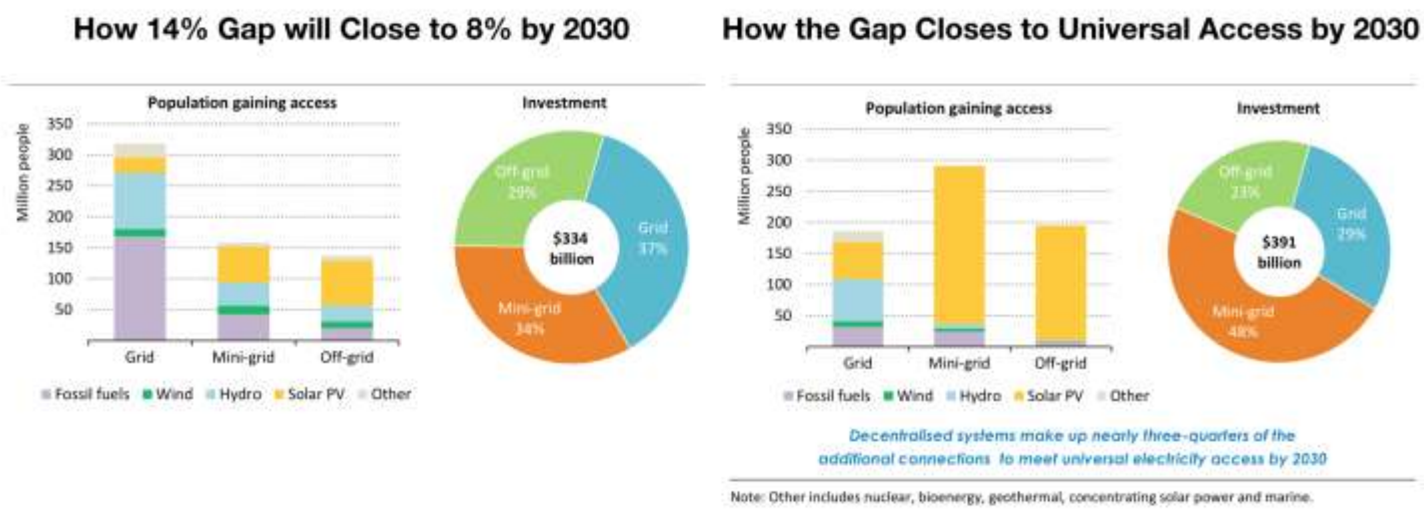

Figure 14: Additional Population Gaining Access and Additional Investment to Achieve such Access
Source: IEA Energy Access Outlook 2017

[128]International Energy Agency, "Energy Access Outlook 2017: From Poverty to Prosperity," accessed October 29, 2018. https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf, pg.39.
[129]*Ibid*., pg. 50-53.

However, even with international efforts at decarbonization, uncertainty lies in the degree to which renewables like solar and wind will be part of the overall energy mix. Moreover, countries may pursue electrification through an approach of energy interdependence, particularly at the regional level, or instead maintain national energy independence. This case study analyzes the potential impact of disrupters such as new methods of energy storage, long distance electricity transmission, and smart grids.

Renewables and the Disruption of the Energy Sector

Renewable energy is available in a broad range of technologies, including hydropower, geothermal, bioenergy, solar, wind and ocean energy. Apart from geothermal energy, these resources are intermittent. Solar and wind power have pronounced variability in particular.[130] The International Renewable Energy Agency (IRENA) reports that renewables grew at an average of 8% yearly since 2010.

Renewables are becoming competitive with fossil fuels on price at a far faster rate than expected and have begun to disrupt the global energy sector. With 25% of renewable energy in global power generation in 2017, renewables may reach 45% of the global mix in 2030 and 60% by 2050.[131]The cost of producing solar and wind energy is expected to continue to plummet (See Figure 15) while coal and traditional nuclear power become costlier.[132] Third generation PVs will be designed for high power conversion efficiency, low cost and efficient use of materials.[133] Concentrated solar power (CSP) plants use mirrors to focus sunlight to supply heat or generate electricity through conventional steam turbines. Compared to PVs, CSP may integrate into existing grids more easily and offer opportunities for electricity export through high voltage lines.[134]

The ability to better generate renewable energy like solar power even more cheaply, store it and transmit electricity at great distances will change the economics of power. Over the long run (by 2050), some scenarios estimate the energy related shipping could decline by 50% for coal, and 25% for oil.[135]

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[130] International Renewable Energy Agency (IRENA), *Planning for the Renewable Future: Long-term Modelling and Tools to Expand Variable Renewable Power in Emerging Economies,* 2017.http://www.irena.org/publications/2017/Jan/Planning-for-the-renewable-future-Long-term-modelling-and-tools-to-expand-variable-renewable-power, pg.18

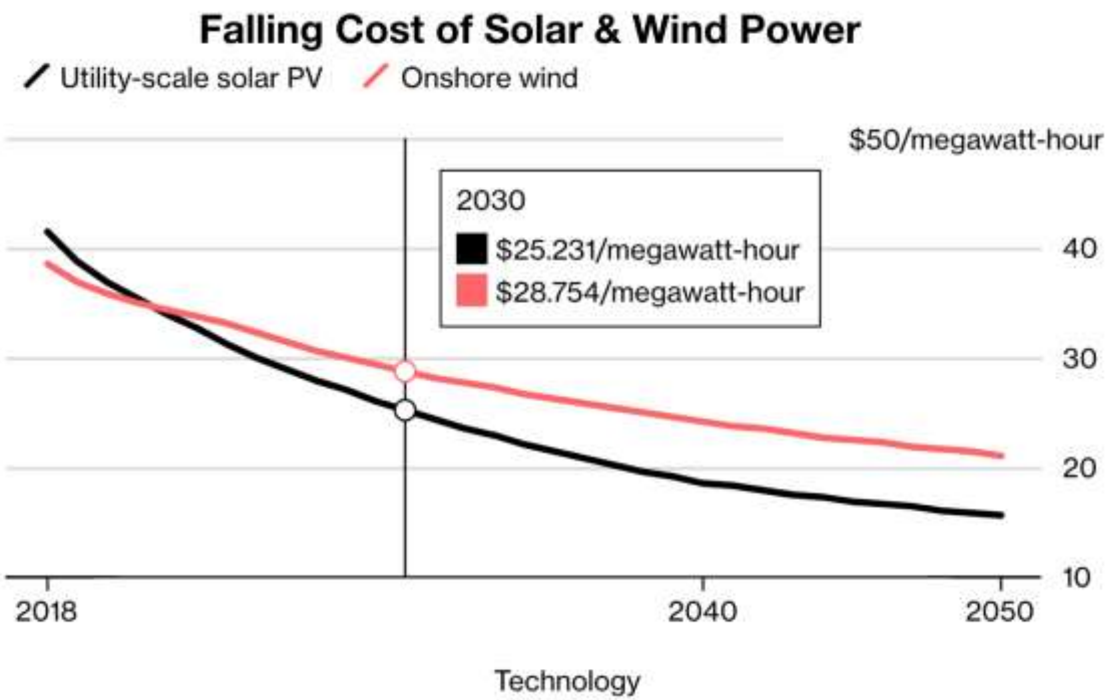
[131] IRENA, *Global Energy Transformation: A Roadmap to 2050*, 2017. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf, pg. 18

[132] Reed Landberg and Anna Hirtenstein, “Coal is Being Squeezed Out of Power by Cheap Renewables”, *Bloomberg*, June 21, 2018, https://www.bloomberg.com/news/articles/2018-06-19/coal-is-being-squeezed-out-of-power-industry-by-cheap-renewables.

[133]United Nations Conference on Trade and Development, “Technology and Innovation Report 2018,” accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 19.

[134] IRENA, *Concentrating Solar Power Technology Brief,* 2015.http://www.irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA-ETSAP-Tech-Brief-E10-Concentrating-Solar-Power.pdf, pg. 2.

[135] Maria Sharmina et. al., “Global Energy Scenarios and their Implications for Future Shipped Trade”, *Marine Policy*, Issue No. 84, 2017, pg. 12.



Note: U.S. forecast, figures show levelized cost which is the end-to-end cost of setting up a power plant

Figure 15: Cost of Renewables (Price per Megawatt-Hour)
Source: Bloomberg New Energy Finance, cited in Landberg and Hirtenstein, 2018

Enabling Full Energy Transition

In order to achieve a transition from fossil fuels to sustainable energy, four pillars of efficient energy systems are needed: dispatchable power stations that adjust their output to fluctuations in net electricity demand, making electricity demand more flexible through the use of smart technology, improving electricity storage and physical networking for high transfer capacity.[136] A combination of renewable energy technology and energy efficiency technology improvements will thus be necessary. Digitalization of the power system will play a central role in combination with new methods of storage and transmission. Decentralized solutions will prevail in less accessible areas.

Responsive power supply and demand

Smart grids promise to help reduce energy usage, improve the process of balancing energy demand and supply, as well as manage energy distribution more efficiently.[137] The IEA observes the rapid adoption of smart meters in China, Europe and the United States while forecasting strong growth in other parts of Asia by 2025.[138] The IEA notes that "smartening" energy systems opens the possibility for real time monitoring of conditions, predicting failures through big data analytics and machine learning.

On the generation side, IoT, big data analytics and machine learning can optimize extensive use of renewables for power generation. "Smart" factories, buildings, residences, vehicles can participate in distributed energy generation. This approach can multiply options, ranging from centralized generation to local smart grids. The large volume of information and varied levels of optimization are likely to encourage processes of non-linear, multidirectional power flows and decision-making,[139] enabling a smart grid to act as more than a set of physical structures and connections and rather as an enabler of energy sector objectives, requiring continuous modernization and innovation.[140]

Improving electricity storage

Intermittent supply from variable renewables like solar and wind energy pose a problem for meeting baseload requirements, the minimum electricity necessary for the economy to run. In contrast, coal, gas and nuclear energy can provide a virtually continuous supply. With the rapid growth in renewables, manufacturers and teams of scientists are racing to offer a solution to store energy to mitigate intermittence. Consequently, the cost of batteries is falling dramatically.[141] At least 14 large battery factories are being built or planned, including Tesla and Panasonic's "gigafactory" in Nevada as well as nine government-backed ones in China.[142]

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[136] Global Infrastructure Connectivity Alliance (GICA), *First Annual Meeting Summary*, 2018, pg. 16-17.
[137] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 9.
[138] International Energy Agency, "Smart Grids: Tracking Clean Energy Process", 2018. https://www.iea.org/tcep/energyintegration/smartgrids/.
[139] Weerakorn Ongsakul, Kun Teng, Sege Marichez, Han Jiang, "An Innovative Idea for Energy Transition Towards Sustainable and Resilient Societies: Global Energy Interconnection", *Global Energy Interconnection*, Vol .1, No. 4, August 2018. http://www.geidco.org/html/qqnyhlwen/col2017080820/2018-08/30/20180830192548548243990_1.html, pg. 314.
[140] Marcelino Madrigal, Robert Uluski and Kwawu Mensan Gaba, *Practical Guidance for Defining a Smart Grid Modernization Strategy: The Case of Distribution* (Revised Edition), 2017. https://openknowledge.worldbank.org/bitstream/handle/10986/26256/9781464810541.pdf?sequence=2, pg. 2.
[141] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg.19.
[142] Pilita Clark, "The Big Green Bang: How Renewable Energy Became Unstoppable", *Financial Times*, May 18, 2017. https://www.ft.com/content/44ed7e90-3960-11e7-ac89-b01cc67cfeec.

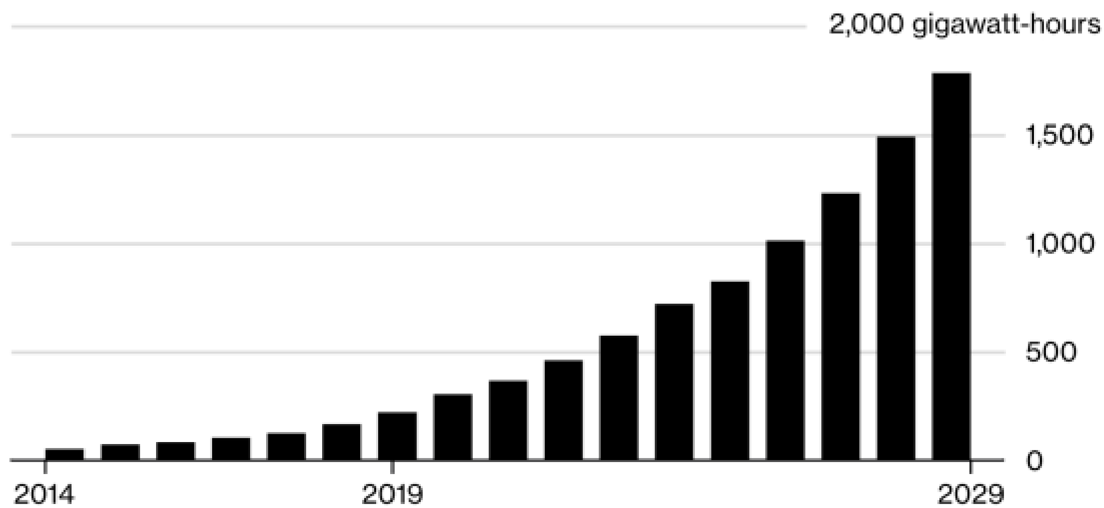

Figure 16: Projected Demand for Lithium-Ion Batteries
Source: Bloomberg New Energy Finance, cited in Hirtenstein, 2018

Some forecasters expect that the capacity for battery manufacturing will triple by 2020, while demand for batteries for electric vehicles and renewable energy storage will rise to 1,784 gigawatt-hours by 2030 from a current level of about 100 gigawatt-hours.[143] The demand for lithium-ion batteries is projected to rise by 1,676% by 2030 (See Figure 16). New technologies for power storage are likely to enter the market after 2025.[144]

Physical networking for high transfer capacity

New high voltage technologies allow for greater interconnection between networks and incorporation of remote energy resources.[145] Ultra-high-voltage-direct-current (UHVDC) lines can carry electricity generated over long distances to where they will be used, at potentially lower

[143] Anna Hirtenstein, "The Battery Boom Could End up Burning Some Investors", *Blooomberg.* August 13, 2018. https://www.bloomberg.com/news/articles/2018-08-13/battery-technology-stranded-asset-debate-green-energy-revolution.
[144] *Ibid*.
[145] International Energy Agency, "Smart Grids: Tracking Clean Energy Process", 2018. https://www.iea.org/tcep/energyintegration/smartgrids/.

cost and greater efficiency than existing technology. Transboundary power trading in renewables can be enabled by interconnected transmission infrastructure to allow grid operators to adjust to intermittent power by moving electricity from where it is generated or unneeded, to where it is required.[146] The Economist reports that China has constructed UHVDC lines since 2010 and the country's State Grid has begun building elsewhere in the world. Moreover, use of the technology is expected to accelerate in India, the United States and Europe by 2020 to 2030.[147] As further impetus for growth, transmission and connector projects have the potential to be primary rather than ancillary investments or by-products of power generation projects.[148]

Uncertainty in Strategies for Decarbonization and Energy Security

Falling prices in renewables and international climate change policy will not automatically pave the way for a sustainable energy future and universal access to electricity. Mitigating the intermittence of renewables is a priority.

Furthermore, decarbonization will be expensive. On the high end of projected decarbonization costs, IRENA estimates that investments totaling US$ 24.6 trillion will be necessary to decarbonize power generation from 2015 to 2050, with another US$ 18 trillion needed for power system flexibility and grid infrastructure, including the expansion of electricity storage, transmission and distribution.[149] IRENA also values potential stranded assets at US$1 to 1.4 trillion for the same period.

Ultimately, an increasing proportion of renewables in the energy mix means a greater need for grid interconnectedness to optimize and stabilize grids, thereby passing on decreasing energy prices to consumers. Renewable energy provides the opportunity for countries and communities to increase their energy independence. Decentralized power generation also means that new infrastructure needs to connect small grids to each other, supplementing larger multi-country grids.[150] Digitalization has the potential to optimize such inter-connection by supporting the trade of energy in two directions across the value chain in multiple country or regional markets.

Regional integration and energy trading can yield a number of benefits to participating countries. Trade can increase regional total surplus and minimize total generation cost, by increasing access to lower cost generation resources and fuels while exploiting synergies between the

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[146] UN Economic and Social Commission for Asia and the Pacific (UNESCAP), *Regional Cooperation for Sustainable Energy in Asia and the Pacific*, 2017.https://www.unescap.org/sites/default/files/publications/REGIONAL%20COOPERATION%20FOR%20SUSTAINABLE%20ENERGY%20IN%20ASIA%20AND%20THE%20PACIFIC.pdf, pg. 39.
[147]*The Economist,* "Rise of the Super Grid", January 14, 2017, https://www.economist.com/science-and-technology/2017/01/14/electricity-now-flows-across-continents-courtesy-of-direct-current.
[148]Weerakorn Ongsakul, Kun Teng, Sege Marichez, Han Jiang, "An Innovative Idea for Energy Transition Towards Sustainable and Resilient Societies: Global Energy Interconnection", *Global Energy Interconnection*, Vol .1, No. 4, August 2018. http://www.geidco.org/html/qqnyhlwen/col2017080820/2018-08/30/20180830192548548243990_1.html, pg. 314.
[149] IRENA, *Global Energy Transformation: A Roadmap to 2050*, 2017. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf,pg. 40.
[150]Global Infrastructure Connectivity Alliance (GICA), *First Annual Meeting Summary*, 2018, pg. 16.

different demand and renewable energy profiles among countries. An aggregated regional renewable profile could be smoother compared to that of an individual country. Pooling resources thus promotes greater flexibility to complement renewable output and provide ancillary services made possible by interconnection (such as spinning reserves, which are extra generating capacity from connected generators). In Sub-Saharan Africa, where the cost of energy supply is among the highest in the world (12c/kWh on average, as high as 25c/kWh in some cases), regional trade may reduce costs by an average of 40%.[151]

The role of the public sector is crucial for interconnecting countries since commercial financing for transmission assets remains difficult. Since 2015, the European Union (EU) has intensified its integration efforts to seek a harmonized EU market by 2030. It aims to create a market in which gas and power flow freely, mitigating climate change and achieving common energy security.[152]

Nevertheless, the creation of energy trading markets depends on whether countries follow a strategy of energy interdependence. Overcoming geopolitical, financial regulatory and administrative challenges is a prerequisite for the success of such a free market approach.[153] Governments often consider energy infrastructure as a matter of national security, pursuing self-sufficiency and consequently imposing restrictions on ownership and trading licenses. The energy sector may be heavily subsidized and closed to market competition, or it may lack access to capital. The regulatory environment may require a regional body or mechanism for price setting, cost-sharing, investment planning and dispute resolution. Technical standards and legal frameworks may be incompatible across borders, moreover. Regulatory barriers have slowed the energy union aims of the EU to build cross-border power interconnections, for instance.[154] There may also be a lack of qualified market operators and there may be a dearth of expertise to manage the complex process of integrating a regional market.

These potential challenges need to be considered in weighing policy options in order to unlock the full potential of these disruptive technologies to meet sustainability goals, decarbonization and universal access to electricity.

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[151] Kwawu Mensan Gaba, World Bank, "Scaling Up Electricity Trade in Regional Power Pools" (PowerPoint presentation), 2018.
[152] European Commission, "Third Report on the State of the Energy Union," accessed November 1, 2018. https://ec.europa.eu/commission/publications/third-report-state-energy-union_en.
[153] *Ibid*.
[154] Anca Gurzu and Sara Stefanini, "State of the (energy) union: How the EU's really doing so far", *Politico*, November 24, 2017. https://www.politico.eu/article/state-of-the-energy-union-how-the-eus-really-doing-so-far/.

Can a Super Grid Based on Renewable Energy Electrify Regions?

Scenario 1:

Member states of a regional economic union could take advantage of progressive improvements in solar PV to build a renewable electricity generation megaproject. The electricity in this scenario would be produced in a few hubs, then traded and distributed across borders. In line with the Global Energy Interconnection model, electricity could be distributed across a network of UHVDC links across several countries.[155] Member states could form a regional body to plan, finance and manage a renewable-powered "super grid", establishing a sophisticated market for electricity trade involving mainly solar and other renewables. Universal access to electricity could be achieved through additional investment in mini-grids. The risk of redundant assets would need to be identified at the start of the project so the group can jointly manage the decarbonization of utilities and ease the transition process.

Scenario 2:

In an alternative scenario in which the technology to enable more stable renewable energy, e.g. high capacity power storage, does not emerge, countries could engage in resource diplomacy for energy trading. In order to decarbonize, countries could increase their use of relatively stable energy sources like hydro-electric power, with limited use of solar and wind power off-grid. The efficiency of energy production and consumption can be achieved through extensive investment in smart grid technology and processes, optimizing electricity generation and distribution. However, universal access to electricity may remain elusive.

Scenario 3:

If creating a regional electricity pool is not viable, individual countries could increase their use of renewables—depending on their solar and wind energy potential. Using decentralized mini-grids could allow them to achieve universal access by 2030. In the country's largest cities, residents could trade energy as "prosumers" (agents who both produce and consume energy) using distributed ledger technology, similar to a pilot project in Bangkok that was eventually replicated and scaled up in many cities worldwide.[156] Even if such countries emphasize self-reliance in their approach to energy security, they could partially meet their energy needs through bilateral power purchases.

[155] Weerakorn Ongsakul, Kun Teng, Sege Marichez, Han Jiang, "An Innovative Idea for Energy Transition Towards Sustainable and Resilient Societies: Global Energy Interconnection", *Global Energy Interconnection*, Vol .1, No. 4, August 2018. http://www.geidco.org/html/qqnyhlwen/col2017080820/2018-08/30/20180830192548548243990_1.html, pg. 314.
[156] Rina Chandran, "In a posh Bangkok neighborhood, residents trade energy with blockchain," *Reuters,* August 28, 2018. https://www.reuters.com/article/us-thailand-renewables-tech/in-a-posh-bangkok-neighborhood-residents-trade-energy-with-blockchain-idUSKCN1LD0Z8.

Policy Recommendations

Solar power and wind energy had already begun to disrupt the energy sector since 2010. If the technology for storage and long-distance distribution of variable renewable energy emerges, the push to decarbonize the energy sector will be even stronger. Energy trade promises many benefits, but a key challenge would be to construct an efficient and effectively governed regional or multilateral market. As far as infrastructure investment is concerned, policymakers would need to recognize stranded asset risks and plan for an orderly transition. Moreover, potential environmental and social challenges as well as security risks need to be mitigated.

Develop an Integrated Regional Market for Energy Trading

For countries willing to form regional power pools, the overall task will be to develop an integrated regional market for energy trading. Integration is a complex process, often requiring confidence building over a long period of time. Granting third party access is often the first step in regionalizing energy trade and network. Openness to this option would allow bilateral arrangements to scale up in the future.

Identify Stranded Asset Risks and Plan for an Orderly Transition

Large-scale financing will be essential to cover large capital costs for solar and wind generation facilities as well as energy storage and transmission network infrastructure. This may require government-backed loans. Participating member countries would need to plan for financial sustainability, especially for an investment of this magnitude. For instance, one assessment of the Gobitec projectin Northeast Asia warned that planners might not have fully estimated the costs of the planned supergrid and network, given its unprecedented scale.[157] Gobitec had been inspired by an earlier European attempt, Desertec, that had eventually failed when investors pulled out in 2012.[158] If the energy megaproject fails, initial investments could become stranded costs. Measures should be taken to mitigate the risks. For instance, the choice of grid infrastructure will need to allow for different energy sources to supply the network.

Managing the potential drop in value of conventional utilities, especially their physical assets, needs to be planned.[159] The possibility of energy storage and transmission technology requires preparation, and the possibility of incorporating assets from the centralized old grid will need to be evaluated. While coal may be relatively inexpensive in the short run, powering economic growth on coal would expose these countries to a high risk of stranded assets in the long term. Although it might be unlikely, the sudden imposition of a regulatory measure (e.g. by international convention or domestic legislation) to drastically curb fossil fuel use would increase the risk of stranded assets even further. Ensuring a greater

[157] Benjamin Sovacool and Christopher Cooper, *The Governance of Energy Megaprojects: Politics, Hubris and Energy Security,* Cheltenham, UK: Edward Elgar, 2013, pg. 201-2.
[158] Selwa Calderbank, "Desertec Abandons Sahara Solar Power Export Dream", *Euractiv*, May 31, 2013. https://www.euractiv.com/section/trade-society/news/desertec-abandons-sahara-solar-power-export-dream/.
[159] Luca de Lorenzo and Pers-Anders Enkvist, "Framing Stranded Asset Risks in an Age of Disruption", Stockholm Environment Institute, 2018. https://www.sei.org/publications/framing-stranded-assets-age-disruption/, pg. 68-78.

share of renewables in the energy mix is an essential balancing policy. Given the likelihood that the cost of renewables will continue to fall, any existing subsidy on fossil fuels will become increasingly difficult to justify.

Set Targets for Access to Electricity

Targets need to be set towards achieving or maintaining universal access to electricity. Even if full access is achieved by 2030, the issue of energy poverty needs to be addressed. In developed economies alone in 2015, an estimated 15% of the total population suffered from a lack of access to modern energy services, a lack of reliability or unaffordability.[160]

Address Environmental and Social Concerns

Any environmental stress resulting from a super grid would need to be mitigated. An UHVDC system will require cooling, for instance; moreover, the construction of large-scale solar projects requires mining for rare earth and metals, which can substantially pollute rivers.[161] Such environmental stress would need to be managed sustainably, if unavoidable. Hydropower entailing large dams may disrupt river flow and entail a severe impact on agriculture, people, biodiversity or spark social resistance.[162] In this scenario, countries should follow established guidance from the World Commission on Dams for avoiding displacement and encouraging positive outcomes in resettlement.[163]

Enhance Cybersecurity

While the use of smart grids is a robust strategy to enhance efficiency in the supply and demand of electricity, the growth of IoT in the energy sector, combined with diversification and decentralization, expands the "attack surface" in the energy ecosystem.[164] Greater integration of energy systems multiplies the risk factor. Given the "low probability-high risk" attacks that could shut down the electricity of a major economic region, the IEA advises a framework for digital security that entails three principles: (i) resilience for continuity of critical infrastructure operations; (ii) cyber hygiene as a precautionary practice; and, (iii) incorporation of security objectives and standards as a part of the design process. The Energy Expert Cyber Security Platform guiding the European Commission, recommends that energy providers cooperate in a threat and risk management system, and offering a framework for vulnerabilities disclosure in the energy sector.[165]

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[160] International Energy Agency, "Energy Access Outlook 2017: From Poverty to Prosperity," accessed October 29, 2018. https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf,pg. 24-25.

[161] Benjamin Sovacool and Christopher Cooper, *The Governance of Energy Megaprojects: Politics, Hubris and Energy Security,* Cheltenham, UK: Edward Elgar, 2013, pg. 199-200.

[162] Brian Richter, et. al., 2010, "Lost in Development's Shadow: The Downstream Human Consequences of Dams", *Water Alternatives,* 3(2): 14-42.

[163] World Commission on Dams, *Dams and Development: A New Framework for Decision-Making. The Report of the World Commission on Dams.* London: Earth Scan, 2000. https://www.internationalrivers.org/sites/default/files/attached-files/world_commission_on_dams_final_report.pdf.

[164] International Energy Agency, "Digitalization & Energy," accessed November 10, 2018. https://www.iea.org/publications/freepublications/publication/DigitalizationandEnergy3.pdf,pg. 121-128.

[165] Energy Expert Cyber Security Platform, "Cyber Security in the Energy Sector: Recommendations for the European Commission on a European Strategic Framework and Potential Future Legislative Acts for the Energy Sector", 2017. https://ec.europa.eu/energy/sites/ener/files/documents/eecsp_report_final.pdf, pg. 64-66.

Mass Customization

In this digitally connected world, consumers can access products and services at their fingertips. This convenience in turn enables the new, burgeoning middle class to customize the products they want to purchase, in order to project their social status and individuality. “Egonomics” subsequently spurs personalization, as businesses becomes customer-centric and cater to their individual needs in order to out-compete their rivals.[166] The advent of additive manufacturing is likely to accelerate this new phenomenon, as it becomes more cost-effective for businesses to cater to each individual customer. Eventually, this is likely to lead to hyper-customization which will in turn affect the way the world is connected. Specifically, global value chains may be disrupted and the types of goods being shipped globally are likely to change.

3D printing could disrupt industries, trade and logistics, although there is a great degree of uncertainty in how the impact of this technology will unfold: mass customization might disrupt the global value chain in one scenario; otherwise, some less disruptive scenarios like 3D printing only for intermediate goods or in low cost locations might occur.

Case Study

KEY MESSAGES

On volumes

- 3D printing allows for greater customization of products, reduced obsolescence, higher production efficiency and shorter time to market
- Between 4.6% and 14.9% of global trade flows may be affected by 3D printing
- Current 3D printing volumes are low (valued at US$7.3 billion) but growing parts of global trade flows will be affected by 3D printing in the long term
- Half of the world’s manufactured products may be made with 3D printers by 2040 leading to some estimates of a high decline in world trade by 38% in 2040
- Monitoring closely the scale and breadth of 3D printing will be necessary to understand its true impact—trends difficult to predict

On connectivity

- The proliferation in the use of 3D printing may cause tectonic shifts in the global value chain
- Manufacturers may re-shore or onshore to be closer to their clients
- Reshoring may have a transformative impact on global freight, as the type of goods being shipped may change from final products to raw material
- The amount of cargo shipped by freight across borders may fall significantly in a high adoption scenario although this may be offset by the growth in the middle class

Planning for cross-border infrastructure

- Support the establishment of 3D printing hubs through incentives
- Create the institutions/mechanisms that specialize in the mediation of conflicts regarding intellectual property rights
- Improve domestic road/shipping/last-mile delivery

[166] Cutter, Phoebe, “Hyper-Personalization Is About To Disrupt Three Major Industries,” July 5, 2017. https://www.forbes.com/sites/phoebecutter/2017/07/05/hyper-personalization-is-about-to-disrupt-three-major-industries/#1a74728611e3.

Additive Manufacturing Today

The use of 3D printing is already a reality in many industries, with the aerospace industry at the forefront of this manufacturing revolution. (See Figure 17) "Among the numerous companies using 3D printing to ramp up production are GE (jet engines, medical devices, and home appliance parts), Lockheed Martin and Boeing (aerospace and defense), Aurora Flight Sciences (unmanned aerial vehicles), Invisalign (dental devices), Google (consumer electronics), and the Dutch company LUXeXcel (lenses for LEDs)."[167] For example, 90 percent of the custom fit hearing aids used today are manufactured using 3D printing.[168]

3D printing market

Sector	2014	Five-year CAGR
Aerospace (including defense)	$0.8 billion 18%	15–20%
Industrial (including construction)	$0.8 billion 18%	15–20%
Health care	$0.7 billion 15–17%	20–25%
Automotive	$0.5 billion 12%	15–20%
Jewelry	$0.5 billion 12%	25–30%
Energy	Less than 5%	30–35%
Other (many sectors)	Less than 20%	20–25%
Total	$4.5 billion	25%

Figure 17: 3D Printing Industry Projected Growth[169]
Source: UNCTAD

[167] D'Aveni, Richard, "The 3-D Printing Revolution," accessed October 18, 2018. https://hbr.org/2015/05/the-3-d-printing-revolution.
[168] UPM, "3D Printing Expert Terry Wohlers: Industry Moving Steadily from Prototyping to Production," April 20, 2018. https://www.upmbiofore.com/biocomposites/3d-printing-expert-terry-wohlers-3d-industry-moving-steadily-from-prototyping-to-production/.
[169] United Nations Conference on Trade and Development, "Technology and Innovation Report 2018," accessed November 1, 2018. https://unctad.org/en/PublicationsLibrary/tir2018_en.pdf, pg. 14.

Table 1 lists the types of products from various industries that are being produced, have been produced (one-off in some cases), or being prototyped/proposed using 3D printing technologies. While non-exhaustive, it is an indicative list for illustration purposes.

Types of Products	Example
Aerospace/Aviation	Airbus's titanium bracket for A350 XWB170 and cabin interior parts[171] Boeing's titanium parts in structural applications for B787[172] GE's fuel nozzles for jet engines[173] Lockheed's titanium fuel tanks for satellites[174]
Fashion	Danit Peleg's clothes[175] (apparel) Adidas Futurecraft[176] (shoes) New Balance's Zante Generate[177] (shoes) Nike Flyprint[178], Nike Vapour series[179] (shoes) Reebok's Liquid Factory[180] (shoes) Kalkul's earphones[181] (music)
Food	Tangible Media Group's flatly-packed pasta[182] Food Ink's 3D-printing restaurant[183]
Furniture	IKEA's "OMEDELBAR" collection[184], "GLÖDANDE" collection[185]
Healthcare	EnvisionTEC's hearing aids[186]

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170 Airbus, "First Titanium 3D-Printed Part Installed into Serial Production Aircraft," September 13, 2017. https://www.airbus.com/newsroom/press-releases/en/2017/09/first-titanium-3d-printed-part-installed-into-serial-production-.html.

171 Airbus, "Bridging the Gap with 3D Printing," April 9, 2018. https://www.airbus.com/newsroom/news/en/2018/04/bridging-the-gap-with-3d-printing.html.

172 Alwyn Scott, "Printed Titanium Parts Expected to Save Millions in Boeing Dreamliner Costs," *Reuters*, April 11, 2017. https://www.reuters.com/article/us-norsk-boeing/printed-titanium-parts-expected-to-save-millions-in-boeing-dreamliner-costs-idUSKBN17C264.

173 Kellner, Tomas, "GE Is Building The World's Largest 'Additive' Machine For 3D Printing Metals," June 20, 2017. https://www.ge.com/reports/ge-building-worlds-largest-additive-machine-3d-printing-metals/.

174 Pappalardo, Joe, "Lockheed Martin Is 3D-Printing Giant Titanium Space Parts," July 13, 2018. https://www.popularmechanics.com/space/satellites/a22129376/lockheed-martin-3d-printing-titanium-fuel-tanks/.

175 "Danit Peleg," accessed October 18, 2018. https://danitpeleg.com/.

176 Adidas, "Futurecraft.4D," accessed October 18, 2018. https://www.adidas.com/us/futurecraft.

177 New Balance, "The Future of Running Is Here," accessed October 18, 2018. https://www.newbalance.com/article?id=4041.

178 Nike, "What Is Nike Flyprint?," April 17, 2018. https://news.nike.com/news/nike-flyprint-3d-printed-textile.

179 "Nike Debuts First-Ever Football Cleat Built Using 3D Printing Technology," February 24, 2013. https://news.nike.com/news/nike-debuts-first-ever-football-cleat-built-using-3d-printing-technology.

180 Reebok, "Reebok Introduces New Liquid Factory," October 24, 2016. https://news.reebok.com/global/latest-news/reebok-introduces-new-liquid-factory/s/8a87d7f7-8a93-49d2-9ddd-efee2d588b76.

181 https://www.kalkul.com/.

182 Wang, Wen, Yao Lining, Cheng Chin-Yi, Zhang Teng, Daniel Levine, and Hiroshi Ishii, "Transformative Appetite," 2017. http://tangible.media.mit.edu/project/transformative-appetite/.

183 Food Ink, "Taste Tomorrow Today," accessed October 18, 2018. http://foodink.io/.

184 IKEA, "Omedelbar," accessed October 18, 2018. https://www.ikea.com/ms/en_SG/ikea-collections/omedelbar/index.html.

185 IKEA, "Glodande," accessed October 18, 2018. https://www.ikea.com/ms/en_JP/ikea-collections/glodande/.

186 EnvisionTEC, "The Top Choice for 3D Printed Hearing Aids, Inner-Ear Devices," accessed October 18, 2018. https://envisiontec.com/3d-printing-industries/medical/hearing-aid/.

Types of Products	Example
	Sonova's hearing aids[187] Align Technology's invisible orthodontics[188] e-NABLE's prosthetics[189]

Table 1: Additive Manufacturing Examples (Non-Exhaustive List)

According to the Wohlers Report 2018, "the additive manufacturing industry, consisting of all additive printing products and services worldwide, grew 21 percent to US$7.3 billion (a growth of US$1.25 billion)", noting 17.4 percent growth in 2016 when the industry reached US$6.1 billion, and 25.9 percent growth in 2015. A total of 1,768 metal additive manufacturing systems were sold in 2017, as compared to 983 systems sold in 2016 – an increase of approximately 80 percent while sellers of industrial additive manufacturing systems also increased from 97 in 2016 to 135 in 2017, globally.[190]

Customer Preferences for Hyper-personalization

Customers are becoming increasingly hyperconnected not just across multiple devices, but also with an array of businesses and products through the growth of the Internet of Things. As a result, customers can now specify what they want in a product or service, i.e. customers now have the power to signal what products an industry should produce. For businesses, this increases competition not just domestically, but also internationally, as technology now enables consumers to transcend borders from the comfort of their homes. Hence, businesses need to focus on personalizing the customer experience to distinguish themselves from their competitors in mid to upper end markets. Frost & Sullivan predicts that, by 2020, customer experience will be the primary determinant of customer loyalty and the key differentiator deciding business's fate.[191]

The personalization of customer experience is already taking place. This is evident in the "way in which Google, Microsoft, Apple and Facebook have begun directing personalized searches, products and news feeds," which "has led to a phenomenon of hyper-personalization that categorizes users into neatly defined clusters based on their search history, buying behavior and social trend."[192] This means that no two users will

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[187]Sonova, "3D Printing Technology for Improved Hearing," accessed October 18, 2018. https://www.sonova.com/en/features/3d-printing-technology-improved-hearing.
[188]Align Technology, n.d. http://www.aligntech.com/solutions/invisalign.
[189]e-NABLE, accessed October 18, 2018. http://enablingthefuture.org/.
[190]McCue, TJ, "Wohlers Report 2018: 3D Printer Industry Tops $7 Billion," June 4, 2018. https://www.forbes.com/sites/tjmccue/2018/06/04/wohlers-report-2018-3d-printer-industry-rises-21-percent-to-over-7-billion/#5c6b31cc2d1a.
[191]Frost & Sullivan,"Customer Experience Management," accessed October 18, 2018. https://ww2.frost.com/consulting/customer-experience/customer-experience-management/.
[192]Kaushik, Preetam, "Tomorrow's Internet: A World of Hyper-Personalized Tribes?," accessed October 18, 2018. https://www.wired.com/insights/2014/03/todays-internet-world-hyper-personalized-tribes/.

see the same results if they had conducted an online search using the same keywords. Wharton researchers found that there is a positive effect on the sales of online businesses from personalized services and recommendation-based purchases. For example, approximately 75 percent of what consumers watch on Netflix comes from the company's recommender system.[193]

Global Value Chain Disruption

Additive manufacturing – the process of making a product layer by layer instead of using traditional molding or subtractive methods – has the potential to drastically change the way products are designed and built, as well as distributed, sold and serviced. 3D printing, as it is more commonly known, allows for greater customization of products, reduced obsolescence of production chains, higher production efficiency and most importantly, shorter time to market by eliminating certain steps in the production process. The overall potential for 3D printing to disrupt trade flows is substantial. Arvis et al. estimate that between 4.6 per cent and 14.9 per cent of global trade flows may be affected by 3D printing.[194]Hence, the existing business model of global logistics and global flows of goods could be disrupted in the following two ways:

First, the mass application of 3D printing could reduce the comparative advantage that emerging markets have in low-cost labor. The local use of 3D printing means that manufacturers may be able to derive higher savings from minimizing manpower costs, and higher production efficiency. Moreover, manufacturers would be able to benefit economically from avoiding tariff liabilities and bypassing the technical barriers in some consumer countries.[195] For example, a Chinese factory that currently exports printable goods to the European Union could reduce transportation and warehousing costs and avoid tariff liabilities at the EU border by first setting up a subsidiary in Germany, and then printing these products and shipping them within the EU instead. As a result, China would see a shift in its comparative advantage from being able to mass manufacture goods using lower cost labor to creating high-value products using 3D printing technology, while Europe would benefit from being relatively more cost-effective overall. This shift in comparative advantage could in turn impact the global logistics industry substantially.

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[193]Girl, DIGIT. "Netflix - Getting Smarter Everyday," September 30, 2015. https://digit.hbs.org/submission/netflix-getting-smarter-everyday/.

[194]Hallward-Driemeier, Mary C.; Nayyar, Gaurav. 2017. *Trouble in the making? : the future of manufacturing-led development (English)*. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/720691510129384377/Trouble-in-the-making-the-future-of-manufacturing-led-development, pg. 137

[195]Zhen, Chen. "The Influence of 3D Printing on Global Container Multimodal Transport System." *Complexity* 2017. Accessed October 18, 2018. https://www.hindawi.com/journals/complexity/2017/7849670/.

On one end of the spectrum, the proliferation of 3D printing could result in a significant shift in the type of goods being transported by container shipping.[196] In this scenario, ships would be more likely to transport raw materials, rather than end products.[197] Given the growing importance of transporting raw materials, this could in turn lead to a decrease in global freight volume relative to the baseline, as manufacturers relocate nearer to their consumers by reshoring or onshoring and reduce the need to ship end products. On the other end, 3D printing may merely serve as a complement to the conventional industry business model.[198] The global maritime industry would simply move to serve a different market segment, as the economics of existing hub activities make it more cost effective for manufacturers to 3D print at existing hubs and then ship the intermediate or final products onwards to the desired destinations. Overall, it remains uncertain how the volume of global freight would be affected, since on one end the growing middle class will demand growing volumes of consumer products and 3D printing is still in its early days in terms of scale.

Barriers to Mass Customization

Cross-Border Cybersecurity Risks

3D printing is susceptible to cybersecurity risks, since the industry's business model relies heavily on digital connectivity and the transfer of digital files across invisible borders. Because the nature of the industry places designs as the key focal point in the "servicification" of manufacturing[199], 3D printing manufacturers will lose revenue if the right mechanisms are not in place to protect their intellectual property rights (IPRs) and the monetary value of their designs from cybertheft. This is akin to how the advent of online streaming and failure to protect their IPRs upended the movie and music industries in early 2000s. In turn, this creates two sets of cross-border challenges associated with 3D printing.

First, the industry's vulnerability to cybersecurity risks raises the question of how borders in cyberspace should be secured, given that perpetrators are increasingly circumventing physical borders to commit crimes. Inherently, this raises the fundamental question of how a cyber border should be clearly defined, and who has the jurisdiction to police the border and enforce the set of laws governing it. While one would assume that governments play an active role in protecting the state from cyber threats, it is currently not the case. Rather, many governments

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[196] Ships&Ports, "3D Printing Could Decimate Container Shipping, Says Auckland Port Exec," May 11, 2018. http://shipsandports.com.ng/3d-printing-could-decimate-container-shipping-says-auckland-port-exec/.

[197] "Global Trends to 2030: Impact on Ports Industry," July 2015. https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/energy-resources/deloitte-cn-er-global-trends-to-2030-en-170104.pdf, Slide 27.

[198] Deutsche Post DHL Group, "2018/2019 Logistics Trend Radar," accessed October 12, 2018. http://www.dhl.com/en/about_us/logistics_insights/dhl_trend_research/trendradar.html#.W2QjBjKFM2w, pg. 21.

[199] *Ibid.*

adopt a passive stance and function mainly in a response role, "investigating after the fact and after an attack has occurred".[200] In fact, the "defense of a nation's cyber frontier is largely left up to private entities".[201] Second, while there are some mechanisms for the protection of IPRs across multiple jurisdictions such as in the European Union, IPRs remain largely protected at the national level on a country-by-country basis.[202] The complexity of international and national IP protection systems means that businesses will incur time and costs to police and enforce their rights in multiple jurisdictions, and to ensure that they themselves do not infringe upon other IPRs.

Cross-Border Trade in Services

Another challenge faced by policymakers pertains to the existing rules of the World Trade Organization (WTO):[203]

- When manufacturers relocate their 3D printing facilities to the country where the products are consumed, WTO agreements such as the General Agreement on Tariffs and Trade (GATT), the Customs Valuation Agreement (CVA), the Trade Facilitation Agreement (TFA), and market access part of the Agreement on Agriculture (AoA) are no longer applicable. This is because these agreements do not apply to the domestically-produced 3D products that are not traded across borders. However, this does not apply to traded goods such as raw materials, spare parts and 3D printers which are still subject to these rules.
- 3D printing can involve a number of different services related activities, such as: (i) designing and engineering computer-aided design (CAD) files; (ii) transferring this digital information; and (iii) establishing online market places where CAD-files can be traded. Services will thus comprise a larger portion of the production processes. As a result, these areas of the production process will now fall under WTO's services-related regulation. However, as General Agreement on Trade in Services (GATS) currently lacks clear or explicit rules on issues related to standards, subsidies, and trade-related investment measures, this affects how services are regulated and how rules are implemented.
- More importantly, it will also be more difficult to use the Dispute Settlement Mechanism (DSM) of the WTO to resolve trade disputes. As the global value chain becomes decentralized with many small players spread out geographically, countries may not find it worthwhile to voice up on behalf of small players as compared to large multinational corporations.

3D Products and Taxes

According to Ernst and Young, the 3D printing industry will reduce Government coffers, given how existing taxation of goods and services is grounded in the physical movement of goods or the provision of services. At the crux of this taxation issue lies the question of where the value

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[200] Osborn, Phillip, "Cyber Border Security – Defining and Defending a National Cyber Border," October 2017. https://www.hsaj.org/articles/14093.
[201] *Ibid.*
[202] Taylor Wessing, "IPR Protection for Cross-Border Trade," April 2017. https://www.taylorwessing.com/download/article-ipr-protection-for-cross-border-trade.html.
[203] Sweden National Board of Trade, "Trade Regulation in a 3D Printed World - A Primer," Sweden National Board of Trade, 2016. https://kommers.se/In-English/Publications/2016/Trade-Regulation-in-a-3D-Printed-World/.

is created, and how Governments should enforce taxation on 3D printed products. If consumers have 3D printers at home, "much of the taxable value may migrate there, where the supply chain ends, greatly reducing the potential for supply chain taxes".[204]

Additive Manufacturing and Sustainability

The environmental impact of 3D printing varies widely, even if only two ends of a spectrum are considered – single-unit prototyping and mass manufacturing.[205] The combination of factors such as printer type, frequency of printer utilization, part orientation, part geometry, energy use and the toxicity of printing materials play a crucial role in determining how environmental sustainability may be enhanced by the adoption of 3D printing.[206]

According to OECD, 3D printing can enable more sustainable material use because: (i) it permits many materials to be shaped in ways previously possible only with plastics; (ii) it lowers barriers to switching between materials by reducing economies of scale in some processes; and (iii) it can allow fewer chemical ingredients to yield more variation in material properties by varying printing processes.[207]

On the contrary, 3D printing could also harm the environment. One potential misunderstanding in the sustainability narrative of 3D printing is the expectation that it will drastically reduce externalities associated with the transportation of goods, because manufacturers will re-shore/onshore to be closer to their clients.[208] However, there is still a need for feedstock materials to be transported, "even for multi-material printers that can print whole products rather than just components."[209] Another misunderstanding is the expectation that 3D printing will automatically be more sustainable, since it eliminates waste whether of final products or input materials.[210] However, 3D printing a product still requires raw materials of high purity that often cannot be recycled.[211] Lastly, energy use in 3D printing is likely to have a large environmental impact. In fact, "increasing energy use per part produced can overwhelm material savings to increase total environmental impacts."[212]

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[204] EY, "In a World of 3D Printing, How Will You Be Taxed?," April 26, 2018. https://www.ey.com/en_gl/trust/in-a-world-of-3d-printing--how-will-you-be-taxed.
[205] OECD (2017), *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris, https://doi.org/10.1787/9789264271036-en., pg. 25.
[206] *Ibid.*
[207] *Ibid.*, pg. 26.
[208] OECD (2017), "3D printing and its environmental implications", in *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris,https://doi.org/10.1787/9789264271036-9-en., pg. 190.
[209] *Ibid.*
[210] *Ibid.*
[211] OECD (2017), *The Next Production Revolution: Implications for Governments and Business*, OECD Publishing, Paris, https://doi.org/10.1787/9789264271036-en., pg. 25.
[212] *Ibid.* pg. 191.

Can 3D Printing Cut Supply Chains Short?

McKinsey estimates that the additive manufacturing sector could generate an economic impact of between US$230 billion and US$550 billion annually by 2025.[213] According to estimates by the ING Group, half of the world's manufactured products may be made with 3D printers by as early as 2040, assuming that the current rate of investment in 3D printing doubles after five years and that the current rate of investment in traditional machines falls by a third after ten years.[214] Based on these assumptions and the assumption that 3D printing is economically viable, one estimate projects that world trade could potentially decline by as much as 38 percent in 2040.[215]

Scenario 1

Through their strong purchasing power, the new global middle class will become the key engine of economic growth by 2030. Their desire to stand out as unique individuals in their society is expected to/could lead them to seek personalized products and services. As a result, there could be a strong, burgeoning demand for ultra-customization. In this scenario, 3D printing technology will have progressed significantly to the point that it is profitable for mass adoption. Manufacturers looking to tap the high demand for 3D printed consumer products are likely to find it cost-effective to re-shore or onshore and to set up regional 3D printing hubs, so that they can be closer to their clients and take advantage of shortened lead times and reduced inventory costs. If this unfolds, there will be a transformative impact on global maritime freight, as the type of goods being shipped changes from final products to raw materials used in 3D printing. As a result, there is likely going to be a fall in the volume of freight across borders relative to a baseline. The overall growth in demand from the middle class is likely to offset it in part.

Scenario 2

If manufacturers find it sufficiently cost-effective to re-shore or onshore so as to take advantage of shortened lead times and reduced inventory costs, but 3D printing technology has not made significant progress for manufacturers to 3D print the final goods, it is more likely that manufacturers will mass produce 3D printed parts (intermediate goods) that will eventually be used in final assembly. Thus, the use of 3D printing would be limited to industrial purposes and the impact on baseline volumes would be limited.

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[213]McKinsey Global Institute, "Disruptive Technologies: Advances That Will Transform Life, Business, and the Global Economy," McKinsey Global Institute, May 2013. https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Disruptive%20technologies/MGI_Disruptive_technologies_Full_report_May2013.ashx, pg. 110.

[214]ING, "3D Printing: A Threat to Global Trade," ING, 8. https://www.ing.nl/media/ING_EBZ_3d-printing_tcm162-131996.pdf, pg. 8.

[215]*Ibid.* pg. 12. See also: World Trade Organization, "2018 World Trade Report - The Future of World Trade: How Digital Technologies Are Transforming Global Commerce," https://www.wto.org/english/res_e/publications_e/world_trade_report18_e_under_embargo.pdf, pg. 93-95.

Scenario 3

Alternatively, 3D printing technology may drive the production costs sufficiently low to enable manufacturers to produce at a distance from customers. This may incentivize manufacturers to 3D-print closer to the consumers in the long run. However, supply side economics may not be sufficient to justify reshoring or onshoring by 2030. At best, there might be some changes in the manufacturers' business model and the volume of goods produced and transported across borders. 3D printed products would still be printed in a low-cost location at a distance away from the consumers and subsequently delivered to them. This might lead to a temporary surge in the freight volume of 3D printed products transported across borders, until manufacturers work out the supply side economics to relocate nearer to the consumers.

Policy Recommendations

Given the potential of additive manufacturing to disrupt the global manufacturing industry, policymakers could facilitate its development to capture some of the opportunities it offers, while preparing for the downside risks associated with new technologies and evolving business models.

Facilitate Trade

To prepare for an increasing volume of 3D printed goods traversing across boundaries, policymakers need to maintain or expand access to overseas markets by supporting trade in goods through tariff reductions, low nontariff barriers (NTB), and efficient logistics.[216] In the same vein, the "servicification" of manufacturing also calls for greater emphasis on reducing restrictions in services, particularly trade restrictions, which tend to be much higher in services than goods and strengthening intellectual property protections."[217]Moreover, as machines become more connected to one another and therefore facilitate international data flows, policymakers would need to ensure that policies governing cross-border data flows are in place.

Strengthen Cybersecurity

Policymakers need to strengthen and enact national or regional cybersecurity plans to counter virtual threats, in order to minimize the risk of online property theft of designs.

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[216]Hallward-Driemeier, Mary C.; Nayyar, Gaurav. 2017. *Trouble in the making? : the future of manufacturing-led development (English)*. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/720691510129384377/Trouble-in-the-making-the-future-of-manufacturing-led-development, pg. 171.
[217]*Ibid.*

In addition, policymakers need to enact policies that recognize and protect the intellectual property rights of businesses to create an incentive for the industry to innovate and thrive. There are already existing protection methods in place, such as quantum dots that prevent counterfeits[218] and DNA marking which allows users to assess if the products are genuine.[219]

Promote International Security Cooperation

Given the cross-border nature of 3D printing, policymakers need to prioritize international cooperation and coordination of national security strategies on dealing with possible crimes associated with 3D printing. Industry players need to participate in the formulation of a common industry policy, so that each player knows his or her role and responsibilities clearly. To mitigate possible national security threats, policymakers could also restrict the creation of certain types of 3D printed products across the entire supply chain, both physically and digitally.[220] The former involves the restriction in the purchase of raw materials that are used to print, while the latter involves the restriction in the access to design files.

Improve Supporting Infrastructure

Policymakers could build or improve existing transport infrastructure to facilitate efficient last-mile delivery of 3D printed consumer goods, if they envision "mass customization" to take place. Moreover, planners could encourage an ecosystem or a special industrial zone/hub wherein suppliers of raw materials, additive manufacturers and companies that create 3D designs are situated in proximity to take advantage of the synergies and exchange of ideas from more frequent interactions amongst these stakeholders. If there currently exists no institution or department within government organizations that specializes in conflict mediation regarding intellectual property rights, policymakers could consider setting them up to build capacity and capability ahead of time for the dawn of mass customization.

Promote Social Inclusion

In the Future of Jobs survey conducted by the World Economic Forum, 3D printing is perceived to have an overall negative impact on employment, with a 0.36 percent decline in employment growth between 2015 and 2020.[221] Given how 3D printing could be a labor-substituting technology, policymakers need to ensure that the displaced workers are equipped with the right skills to take on manufacturing jobs higher up in the value chain. This may include providing monetary incentives to these workers to take up courses to upskill or re-skill. In addition, to ensure that the economy is well prepared for the disruption in manufacturing, policymakers also need to create a pipeline of manpower that is well-equipped with the relevant design skills to take up related jobs. This may be in the form of compulsory subjects weaved into the education curriculum, or the introduction of courses in tertiary and vocational institutions.

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[218] Milkert, Heidi, "Quantum Materials Corporation Secures Technology to 3D Print Quantum Dots for Anti-Counterfeiting," June 30, 2014. https://3dprint.com/7701/quantum-dots-3d-print/.
[219] Hornick, John, "How to Tell What's Real and What's Fake in a 3D Printed World," February 5, 2014. https://3dprintingindustry.com/news/tell-whats-real-whats-fake-3d-printed-world-23219/.
[220] *Ibid.*
[221] World Economic Forum, "Employment Trends," accessed October 18, 2018. http://reports.weforum.org/future-of-jobs-2016/employment-trends/.

Advance Environmental Sustainability

To promote environmental sustainability in the industry, policymakers could utilize monetary incentives to entice manufacturers to adopt low-energy printing processes and to use low-impact materials with useful end-of-life characteristics.[222] They may also establish a voluntary certification system that labels 3D printing systems according to their environmental impact ("greenness"), so that buyers can make informed decisions on their purchases.

Consider Taxing 3D Printed Products

To mitigate potential shocks from a sudden contraction of cross-border trade, policymakers could look for alternate income channels to replace possible lost tax revenue, if it proves too difficult to implement and monitor the taxation of 3D printed products.

[222]Hallward-Driemeier, Mary C.; Nayyar, Gaurav. 2017. *Trouble in the making? : the future of manufacturing-led development (English)*. Washington, D.C. : World Bank Group. http://documents.worldbank.org/curated/en/720691510129384377/Trouble-in-the-making-the-future-of-manufacturing-led-development, pg. 26.

Where do we go from here?

This draft GICA Outlook represents a first step at inviting GICA Members, governments, multilateral development banks, international organizations, industry associations and other global connectivity experts to craft policy recommendations in the face of potential disruption. The GICA Secretariat will organize a virtual discussion on LinkedIn to solicit further inputs on the framework, estimating the impact of disrupters and additional, instructive case studies. Cooperation on expanding and deepening this analysis is sought from GICA Alliance members and other experts in the various sectors covered here.

Annex A: Current Volume of Flow for Energy, ICT, Transport and Trade Sectors

Sector	Measurement [Year]	Statistics	Source
Energy	Global cross-border trade in oil [2017]	68 million barrels daily	https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf,page 24
	Global cross-border trade in oil [2017]	3.32 billion tons	https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf,page 26
	Global cross-border trade in natural gas (by pipeline) [2017]	741 billion cubic meters	https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf,page 37
	Global cross-border trade in natural gas (as liquefied natural gas) [2017]	393 billion cubic meters	https://www.bp.com/content/dam/bp/en/corporate/pdf/energy-economics/statistical-review/bp-stats-review-2018-full-report.pdf,page 37
	Global seaborne trade in coal [2016]	1.14 billon tons	https://unctad.org/en/PublicationChapters/rmt2017ch1_en.pdf, page 10
ICT	Estimated increase in GDP from global cross-border data flows [2014]	US$2.8 trillion	https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Digital%20globalization%20The%20new%20era%20of%20global%20flows/MGI-Digital-globalization-Executive-summary.ashx, page 1
	Total used intraregional bandwidth [2014]	141 Tbps	https://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/digital-globalization-the-new-era-of-global-flows
	Total used interregional bandwidth [2014]	70.5 Tbps	https://www.mckinsey.com/business-functions/digital-mckinsey/our-insights/digital-globalization-the-new-era-of-global-flows
	Global cross-border trade in IP-related services [2017]	US$381 billionof global exports of other commercial services	https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018chapter04_e.pdf, page 52
Transport	Total number of international passengers	1.6 billion	https://www.icao.int/annual-report-2017/Documents/Annual.Report.2017_Air%20Transport%20Statistics.pdf, page 2

	carried on scheduled air services [2017]		
	International scheduled passenger traffic [2017]	4,861 billion passenger-km	https://www.icao.int/annual-report-2017/Documents/Annual.Report.2017_Air%20Transport%20Statistics.pdf, page 2
	International air freight [2017]	37 million tons	https://www.icao.int/annual-report-2017/Documents/Annual.Report.2017_Air%20Transport%20Statistics.pdf, page 2
	+Number of scheduled flight departures [2017]	36.7 million	https://www.icao.int/annual-report-2017/Pages/the-world-of-air-transport-in-2017.aspx
	International Freight by Volume (Rail) [2015]	4,603 billion ton-km	https://www.ttm.nl/wp-content/uploads/2017/01/itf_study.pdf, page 75
	International Freight by Volume (Road) [2015]	7,577 billion ton-km	https://www.ttm.nl/wp-content/uploads/2017/01/itf_study.pdf, page 75
	International Freight by Volume (Maritime) [2015]	79,715 billion ton-km	https://www.ttm.nl/wp-content/uploads/2017/01/itf_study.pdf, page 75
	Global maritime trade volume (all cargoes) [2017]	10.7 billion tons	https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf, page 5
	Global maritime trade volume (crude oil, petroleum products and gas) [2017]	3.15 billion tons	https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf, page 5
	Global maritime trade volume (main bulks) [2017]	3.2 billion tons	https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf, page 5
	World containerized trade volume [2017]	148 million TEUs	https://unctad.org/en/PublicationsLibrary/rmt2018_en.pdf, page 12
Trade	Global e-commerce [2016]	US$27.7 trillion	https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018chapter02_e.pdf, page 21
	Cross-border e-commerce shoppers [2014]	360 million	https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Digital%20globalization%20The%20new%20era%20of%20global%20flows/MGI-Digital-globalization-Executive-summary.ashx, page 9

	Cross-border online workers [2014]	44 million	https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/McKinsey%20Digital/Our%20Insights/Digital%20globalization%20The%20new%20era%20of%20global%20flows/MGI-Digital-globalization-Executive-summary.ashx, page 9
	World merchandise exports [2017]	US$17.73 trillion	https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018chapter03_e.pdf, page 27
	World commercial services exports [2017]	US$5.28 trillion	https://www.wto.org/english/res_e/statis_e/wts2018_e/wts2018chapter03_e.pdf, page 27

Note: Unless stated otherwise (by +), all the figures provided in the table above reflect cross-border flows.