



# WORKING PAPER



## Emerging and exponential technologies: New opportunities for low-carbon development

by Benjamin Combes, Darius Nassiry, Lizzy Fitzgerald and Tarik Moussa



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Bogota, Columbia

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## Executive summary

This paper discusses how new technologies can contribute to achieving climate change goals in developing countries, focusing on how emerging and exponential technologies can support, and potentially accelerate, the implementation of Nationally Determined Contributions (NDCs) under the Paris Agreement<sup>1</sup> within the broader context of low-carbon, climate-resilient development.

The Fourth Industrial Revolution (4IR) – the dynamic economic transformation now under way, driven by disruptive new technologies and business models – is projected to affect many production and consumption systems, with far-reaching implications for the environment, economies and society.<sup>2</sup> Building on the Third Industrial Revolution (3IR) – which began with personal computing, expanded to mobile phones and the Internet, and has reshaped entire sectors of the economy – the 4IR is expected to have similarly broad impacts, including profound economic impacts over the coming decades.

Emerging 4IR technologies include advanced materials, artificial intelligence, autonomous vehicles, big data, cloud computing and the Internet of things, as well as other new digital technologies. The advancement of these technologies will bring about a period of technology-driven change that is of unprecedented speed, scope and scale. This will correspond with efforts to implement the Paris Agreement and other climate change strategies, and to fulfil the Sustainable Development Goals.

This dramatic shift in technologies will be accompanied by similar transitions in business models and social systems. Policy-makers, development planners and other stakeholders will play a key role in shaping whether the 4IR can be harnessed to help their countries achieve their NDCs. It will therefore be important for decision-makers, in both the public and private sectors, to understand the potential of new technologies to advance climate change and development objectives, and maximise benefits while minimising transition risks.

Today, the prices of renewable energy and battery storage technologies are declining steadily and their diffusion is growing, in many places replacing older technologies such as those dependent on fossil fuels. This provides an early example of how the 4IR will potentially have long-term impacts on incumbent technologies. How can policy-makers leverage the value of the next wave of 4IR technology innovations for low-carbon, climate-resilient development? Should they plan for a lower-carbon version of today's economy – or a fundamentally different future economy, one that may be much more efficient thanks to these new technologies? Can we create a 4IR-enabled world that will address climate change, improve sustainability and minimise economic inequality?

For many developing countries, emerging 4IR technologies may seem remote or even irrelevant compared to their urgent and immediate growth and development priorities. However, the rapid pace of change is likely to open up new options, creating alternative pathways to support economic growth and social development, and help them pursue a low-carbon future. For example, 4IR technologies can broaden emissions-reduction options in infrastructure-intensive sectors (e.g. energy and transport) where long-lived investment decisions are already being made.

In view of this potential to contribute to climate and development goals, this paper explores how 4IR technologies could affect NDC planning and implementation. It summarises the current knowledge and experience of a set of new technologies and their emerging applications for climate change mitigation, focusing on the NDCs from six of the Climate and Development Knowledge Network's (CDKN) priority countries – Bangladesh,<sup>3</sup> Colombia,<sup>4</sup> Ethiopia,<sup>5</sup> India,<sup>6</sup> Indonesia<sup>7</sup> and Kenya<sup>8</sup> – and highlighting goals and strategies related to 4IR technologies in the energy, transport, production and consumption, land-use and building sectors. Potential applications of 4IR technologies are considered at the sector level, based on desk research and interviews with CDKN experts. Challenges and opportunities for maximising the 4IR in developing countries are then discussed. Finally, we put forward a set of preliminary conclusions and recommendations.

Given many 4IR technologies are in the early stages of development, the evidence base is limited and our conclusions are therefore preliminary. This research represents an initial step towards helping climate and development policy-makers to engage with the possible implications of these technologies for achieving sustainability and meeting climate change goals. While this paper focuses on the planning

and implementation of the NDCs, we recognise that these represent only part of national development planning processes and climate change actions in some countries. Current findings suggest that some developing countries are already deploying 4IR technologies, but in pursuit of other goals rather than climate change objectives.

It is important to note that this research emphasises the potential for new technologies to contribute to climate change *mitigation*, as it seems that many potential applications of 4IR technologies tend in this direction. However, they may also lend themselves towards adaptation or resilience applications (e.g. nano-satellite imagery for tropical forest preservation). We have highlighted some potential technology applications for climate adaptation and resilience, recognising that these are also urgent for many developing countries.

We hope that this paper will help policy-makers, development planners and other stakeholders to consider the potential for emerging and exponential technologies to contribute to NDC implementation. It was written to initiate – not conclude – discussions on the opportunities that will arise as the 4IR evolves. Technologies and processes that we cannot currently envisage – the ‘unknown unknowns’ – will also evolve, and may offer the potential for structural and other paradigm shifts that are beyond our current understanding. There will also be risks: disruptive technologies will not always be welcome models for technological change, particularly in local markets where employment prospects may be poor and technical skills lacking. Only by fully assessing and understanding this emerging revolution can the challenges and opportunities be properly assessed and monitored.

We welcome further engagement with stakeholders from developing and emerging economies, to explore the links between new technologies, climate change and development, and to further develop knowledge and thinking in this area.

## Harnessing emerging technologies for climate compatible development

### Overview and approach

As we approach the third decade of the 21st century, rapid technological change is coinciding with the implementation of commitments to help address climate change and achieve global sustainability goals. Decarbonisation is a key driver of technological change and deployment,<sup>9</sup> and emerging technologies have the potential to contribute significantly to, and expand on, emissions-reduction targets if designed and scaled in a ‘smart’ and sustainable way. Many emerging and exponential technologies are part of what is described as the Fourth Industrial Revolution (4IR).

The role that technology can play in reducing emissions and enhancing resilience has been an important theme in international climate negotiations since the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties in 1992, through to the Paris Agreement and the present day.<sup>10</sup> Nearly 140 countries mention technology in their Nationally Determined Contributions (NDCs), with more than 100 countries indicating that they need international support for technology development and transfer to implement their NDC.<sup>11</sup> In this paper, we consider, on a preliminary basis, the potential implications of this for implementing the NDCs, and how these new and emerging 4IR technologies can facilitate and improve prospects for climate compatible development more widely.

The increasing cost-effectiveness of renewable energy technologies (e.g. solar, wind and batteries) over the past few decades demonstrates the transformative potential of new developments in low-carbon technologies.<sup>12,13</sup> Efforts to extend current dynamics and improve the technology, alongside greater economies of scale and falling prices, will continue to drive the expansion of renewable energy and support the decoupling of greenhouse gas emissions from economic growth.<sup>14</sup> As other emerging 4IR technologies (e.g. cloud computing, artificial intelligence and autonomous electric vehicles) develop and reach commercial scales, prices for these are expected to follow a similar trajectory.<sup>15</sup> This creates an opportunity for their application at scale in developing countries.

As these technologies mature and are combined with one another, they will have the potential to transform industries and markets, disrupting incumbent technologies and business models, and generating opportunities for new entrants. Such developments could have significant implications, for

example lowering investment requirements and shifting the timing of technology investment decisions, or opening up the possibility of delivering more ambitious emissions reductions across a range of systems, such as energy, manufacturing, agriculture and transportation.

At the same time, all countries must find ways to address the social and economic dislocations that technology development and deployment might bring. These include potentially far-reaching political and economic consequences for developed and developing countries, due in part to the distribution of benefits and social and financial effects. For example, systemic change can create ‘winners’ and ‘losers’; how countries manage this transition in coming decades – including maintaining employment and ensuring that new technologies help with this – will play a major role in determining whether they enjoy broadly shared benefits or face political resistance due to rising inequality or inadequate social inclusion.

The need to recognise the importance of the political economy of the NDCs and broader climate and development planning, and of technology adoption, should not be underestimated. This represents a key success factor which, in our view, will differ depending on the specific social, economic and policy conditions in each country. An essential part of the debate around the role of 4IR technology in climate and development planning is analysis of the technology options available and their associated issues. Therefore, rather than address the context-specific political economies of national planning and technology adoption, this paper aims to provide a systematic analysis of the development implications of 4IR technologies.

In its earlier *Tech breakthroughs megatrend* report,<sup>16</sup> PwC screened over 150 technologies likely to be mainstreamed over the next decade to identify the ‘essential eight’ with the highest potential global, cross-sector business impact in the next five to seven years. Building on this, we use the same dataset to focus on technologies that can address sustainability challenges. We have added two additional technologies to the list – synthetic biology and advanced materials, which tie directly to low-carbon breakthroughs – which we rename the ‘ten exponential 4IR technologies’, shown in Figure 1 (see Appendix 1 for further details).

The 4IR is beginning to take hold in advanced economies, but its consequences for employment, wealth creation and distribution are not yet fully understood. Given that many of these new technologies are in the nascent stage of development, we have taken a broad view in our analysis of how to harness them for climate compatible development, assessing the available literature and drawing on our own expertise. Further research and analysis are required to better understand the more detailed cost implications and emissions-reduction potential of particular technologies.

### New technologies for the NDCs

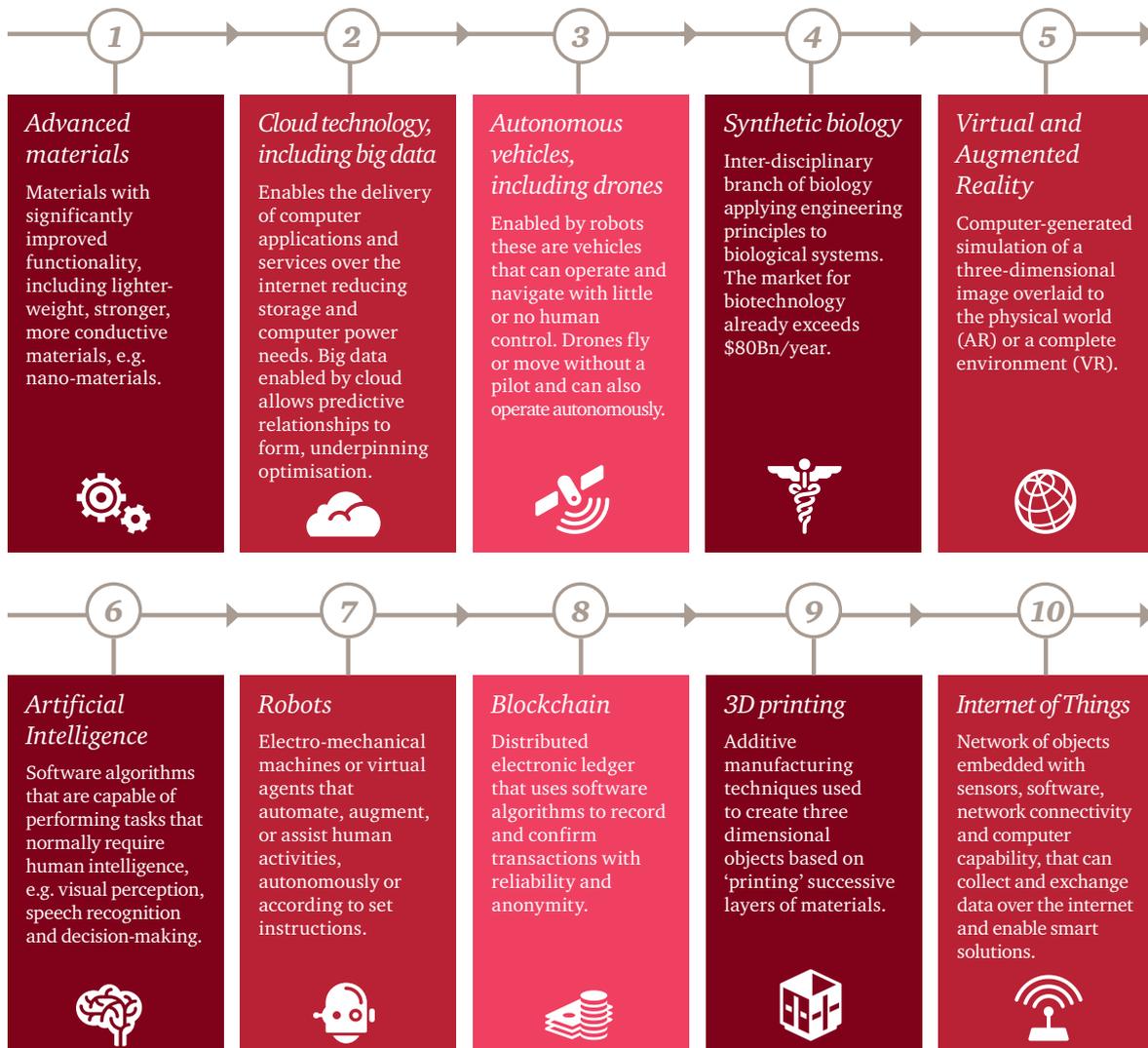
The *Innovation for the Earth* report<sup>22</sup> describes how the next wave of 4IR technologies has the potential to contribute to sustainability goals. Together with other exponential technologies, including renewable energy, these can change patterns of economic activity and thereby lower emissions and accelerate the low-carbon transition required to achieve the NDCs.

The NDCs and other forms of development planning also create an opportunity for developing countries to prepare for the future now, or risk a widening technology gap.<sup>23</sup> The next decade will be particularly important: by 2030, investment worth around US\$90 trillion is needed in the world’s urban, land-use and energy infrastructure systems.<sup>24</sup> The International Energy Agency indicates that US\$44 trillion of investment will be needed in global energy systems alone, with the bulk of investment in non-Organisation for Economic Co-operation and Development countries expected to account only for the increase in primary energy demand by 2040.<sup>25</sup>

As the economics of emerging and exponential 4IR technologies continue to improve, they will broaden the options for policy-makers to achieve the goals of the Paris Agreement. They are also relevant for NDC policy-makers and development planners now, and in three ways:

- **For NDC policy-makers already putting plans into action**, 4IR technologies offer a chance to rethink the path forward and ask whether they may offer better, more resilient near- and medium-term solutions from an efficiency, economic and performance standpoint, compared to the technologies currently in widespread use.

Figure 1. Ten exponential 4IR technologies



Source: PwC *Innovation for the Earth*

### Box 1. Emerging and exponential technologies

An *emerging technology* is one that has not yet reached the commercial deployment stage. As Rotolo et al. (2015) state, it is “a radically novel and relatively fast growing technology characterised by a certain degree of coherence persisting over time and with the potential to exert a considerable impact on the socio-economic domain(s) which is observed in terms of the composition of actors, institutions and the patterns of interactions among those, along with the associated knowledge production processes. Its most prominent impact, however, lies in the future and so in the emergence phase is still somewhat uncertain and ambiguous”.<sup>17</sup>

An *exponential technology* is characterised by continuous improvement in price and/or performance per unit of price over time. More specifically, “the power and/or speed doubles each year, and/or the cost drops by half”.<sup>18</sup> For example, in silicon chip manufacturing, Moore’s Law<sup>19</sup> states that the number of transistors per square inch on integrated circuits doubles approximately every 18 months. In the energy sector, Swanson’s Law for solar power holds that “the cost of the photovoltaic cells needed to generate solar power falls by 20% with each doubling of global manufacturing capacity”.<sup>20, 21</sup> Box 2 discusses renewable energy technologies as examples of exponential technologies.

- **For policy-makers less advanced in their NDC planning**, who have not yet fully detailed how broad NDC goals will translate into action plans and strategies, 4IR technologies create new opportunities to expand their options as they develop implementation plans; these should also be integrated into wider economic and social development planning.
- **For technology innovators**, NDC targets and the decarbonisation pathways needed to fulfil the Paris Agreement offer new opportunities to identify and develop combinations of technologies that can allow countries, regions and cities to decarbonise faster than is currently possible. Nowhere is this opportunity greater than in developing and emerging economies, which have the potential to 'leapfrog' economies more encumbered by existing infrastructure.

Network effects can create opportunities to switch systems or leapfrog previous patterns of economic development by speeding up adoption. This occurs as more users of a given system increase the value of being on the same system, while also increasing the cost of *not* being on the system. Recent examples include mobile phones and social media. In the future, it may include autonomous electric vehicles: as more people shift to these, there will be benefits to engaging while the costs (e.g. higher insurance and maintenance costs) will begin to accrue to those remaining on the previous system – which will lead to further adoption. 4IR technologies are likely to follow this dynamic, particularly where conditions are supportive of both initial adoption, and scaling deployment and diffusion.<sup>26</sup>

### Planning for an inclusive transformation

Countries have always faced a continual process of structural change as they contend with challenges and opportunities from rising incomes, increasing urban populations and maturing economic structures.<sup>40</sup> Developing and developed countries must now respond to climatic change and exponential technological development as well. While the 4IR is emerging in a cluster of tech-enabled advanced economies, it is likely to expand across the world quickly.

This is partly enabled by the rise and increasing penetration of the Internet and mobile technology. As the world becomes more connected and digitally enabled, technology is becoming increasingly central in driving economic growth and development. But the public sector can also play a crucial role in shaping markets at each stage of technology innovation, development and diffusion, through policy and purchasing power.<sup>41</sup> Technological readiness and capacity for adoption are particularly important in driving and managing structural change.

The process of structural change creates winners and losers, however. Given the 4IR is likely to advance at an unprecedented pace, planning for the implementation of 4IR technologies will be essential to ensure broader sustainability goals are bolstered, not hindered.<sup>42</sup> Even with careful planning and implementation, overcoming issues linked to political economy will be a significant challenge and will likely differ by country, depending on their circumstances. Political economy considerations therefore need to be embedded into policy design and development to create the right enabling environment, and solutions will need to be made on a country-by-country basis.

As the scale of the policy response required to manage the 4IR becomes clear, initiatives and programmes are emerging to ensure this transition helps to achieve the Sustainable Development Goals.<sup>43</sup> New programmes include the World Economic Forum's '4IR for the Earth' initiative,<sup>44</sup> the recent G20 policy briefs<sup>45</sup> and statements, and other public-private partnerships (e.g. the Partnership on Artificial Intelligence<sup>46</sup>) which recognise and aim to address the challenges of this transition.

When considering potential sustainability applications of the 4IR, with a focus on climate change, it is crucial to consider broader societal consequences that the growing availability of these technologies could bring. One recent study on the US labour market indicated that up to 47% of total US employment could be at risk from automation,<sup>47</sup> for example through haulage jobs lost by a shift to automated road transport, a machine-led Internet of things replacing manufacturing jobs, and smart agriculture replacing rural jobs.<sup>48</sup> The impacts of automation are likely to be significant for developing countries too, and studies on this topic are starting to demonstrate the extent to which automation might impact growth and development.<sup>49</sup>

## Box 2. Renewable energy: An exponential technology

In recent years, the prices of technology options in the energy sector – including renewables – have fallen significantly as economies of scale expand, and continued innovation and improvements reduce the associated costs. For example, prices for solar photovoltaic (PV) systems, wind power and battery storage technologies have reduced consistently over the past decade: the levelised costs of solar PV<sup>27</sup> have fallen 85% over the past seven years,<sup>28</sup> wind energy prices have dropped by 65%<sup>29</sup> and battery costs per kilowatt-hour have decreased by 75%.<sup>30</sup>

Plotted over time, these price falls are more consistent with the exponential rate of change of digital information technologies, rather than fossil fuels or other energy infrastructure.<sup>31</sup> And while renewable technologies still represent a small proportion of today's global energy system, their growth and marginal effects may result in a faster transition than many currently expect, with potentially disruptive impacts on fossil fuel incumbents and financial markets.<sup>32</sup>

Renewable energy technologies have rapidly become cost-competitive with incumbent technologies, and as prices fall further, they will become increasingly attractive. This creates a virtuous cycle in which each successive wave of innovation builds on prior waves, multiplying the impacts that can accelerate change. The speed of this transition is increasingly being driven by rapid progress in other digitally enabled technologies, including advanced materials, autonomous vehicles, artificial intelligence, big data, cloud technology and the Internet of things, in terms of both technological development and cost projections.

The potentially profound economic impacts of renewable energy are not new; they are similar to the invention and widespread use of the steam engine (1IR), the expansion and improvement of electric power (2IR) and the advancement of digital and computer technologies (3IR). These all caused 'ripples' across economies, altering economic structures. Dramatic reductions in the cost of renewables have already changed investment patterns<sup>33</sup> and the basic concepts of modern energy systems,<sup>34</sup> and renewables still have the potential to increase distributed power and self-generation, and enhance power management.

In this way, renewable energy offers a possible preview of the impacts of other 4IR technologies.<sup>35</sup> Driven by computing power, digital distribution and new combinations to boost performance and efficiency, other 4IR technologies could see similar reductions in cost and performance trajectories as they develop and scale, because of similar underlying dynamics – or even faster rates of change due to previous advances. As a result, options to realise a low-emissions future economy may expand rapidly.

As well as this evidence from the energy sector, early signals from other 4IR technologies suggest continued reductions in cost and improvements in performance.

- Lifelike 'humanoid' robots are more than 75% cheaper than they were in 2009.<sup>36</sup>
- Cloud storage technology prices dropped by up to 8% from October 2013 to December 2014.<sup>37</sup>

The disruption of previously secure markets and industries is already under way. Companies such as Amazon, Uber and Airbnb exemplify a new digital economy where entrants can quickly gain market share, building on network dynamics and digital platforms without the need to own physical inventory, cars or property. New entrants may start with only a single-digit market share, but falling prices and improving quality can lead to a tipping point where their cost-competitiveness, ability to adjust quickly and other advantages speed up adoption. This pattern is also emerging in the energy sector, where renewable energy technologies now threaten to displace fossil fuels.<sup>38</sup>

Switching to new technologies becomes less a matter of *whether* a transition will take place, but rather *when* – the extent of and timescale for technology disruption. However, due to the speed of progress, there is a window of opportunity to plan for technology adoption, before suboptimal options are locked in and investment decisions are taken. The window for 4IR developments is now.

As Figure 2 shows, technologies typically follow an S-curve of adoption, starting slowly and accelerating to a steady state.<sup>39</sup> Early adopters represent a negligible market share at first, and technologies may seem comparatively expensive. However, these early adopters help to improve the technology through market feedback, and set the stage for continued price declines, which are realised by growing scale in deployment, continued innovation in design and materials to increase commercial results, and convergence with complementary technologies. Business models drive price declines and foster the development of a supportive technology ecosystem. As prices continue to decline, progress in price per unit continues to improve, leading to an accelerating pace of adoption as the technology becomes widespread.

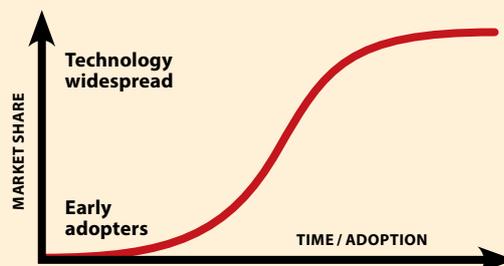


Figure 2. S-curve of adoption

### **Box 3. How blockchain technology can build a more inclusive future**

Blockchain is a distributed electronic ledger technology that uses software algorithms to record and confirm transactions with reliability and anonymity. Early examples, which include cryptocurrencies such as Bitcoin, suggest that use-cases of distributed ledger technology can help broaden financial inclusion, improve transparency and reduce costs. This has the potential to improve the accuracy, efficiency and reliability of property ownership, access to finance, and remittance flows.<sup>52</sup>

To ensure an inclusive, fair transition, policy-makers must anticipate how to design and manage the transition process. If they do not, there is the potential for applications to appear – or even be imposed – with limited or no engagement with developing country policy-makers.<sup>50</sup> For example, drones can already be used to plant trees; it is possible to imagine the implementation of a remote-controlled plantation,<sup>51</sup> using drones and the Internet of things, in which a range of temperature, precipitation and soil condition data are monitored and controlled remotely.

Countries therefore face not only the opportunities from 4IR technologies, but also risks from not engaging. These include the increased likelihood of higher costs due to lock-in to obsolete technologies and uneconomic technologies, the risk of investments being stranded in these, and greater potential for social dislocation as workers are trapped in shrinking industries that are no longer competitive. The extent to which technology transfer can take place and foster long-term employment and development involves numerous challenges, including how developing countries acquire and retain the technological know-how and capacities that they need to gain and use these new technologies, or manufacture and adapt these to local conditions. These important challenges are touched upon in this paper and warrant further research and analysis.

If well planned and well implemented, however, 4IR technologies can facilitate a more economically inclusive future (see Box 3). Careful planning, foresight and policy-making will be needed, however, to ensure a sustainable and inclusive transformation, particularly in view of the political economy challenges of managing the flow of resources from slow-growing to fast-growing sectors while balancing the interests and needs of both incumbents and (potential) new entrants to markets and economic sectors.

### **Mapping emerging technologies for NDC planning**

#### **Challenges and opportunities: 4IR technologies for NDCs**

The current NDCs were submitted to the UNFCCC as Intended Nationally Determined Contributions in 2015 under the Paris Agreement. They may not, therefore, fully reflect the potential for technological progress during the implementation period (the Paris Agreement will be implemented from 2020, and NDCs will be reviewed every five years from then on). However, the range of emerging technologies represent an opportunity to revisit, and possibly increase, the low-carbon ambitions set out in the NDCs.

This does not diminish the significant potential hurdles in deploying 4IR technologies, however, which include existing infrastructure constraints, current levels of technological readiness, and the financing available for investment. In view of the exponential rate of technological change – particularly given recent experience in the energy sector – NDC planners in developing and developed countries should consider 4IR developments now, as they plan their countries' future economy-wide and sectoral trajectories.

The NDCs vary greatly in terms of their sectoral coverage and the level of detail around commitments and goals. Given this variance, we reviewed six NDCs – from Bangladesh, Colombia, Ethiopia, India, Indonesia and Kenya – to identify cross-cutting themes across sectors, with a focus on sectors that generate significant contributions to emissions reductions. These six are part of CDKN's portfolio of priority countries, which has allowed us to draw on CDKN's experience of working with their policy-makers.

Our analysis presents a high-level synthesis of the NDCs analysed, and may not fully reflect the nuance contained within each. In addition, each of our six countries has prepared, or is drafting, more detailed climate change response plans – Bangladesh, for example, is in the final stages of producing its NDC

sectoral action plans – which have not been considered in this paper. We welcome any feedback on different interpretations of the NDCs for subsequent consultation and follow-up work.

Our synthesis is separated into five sectors: energy; transport; production and consumption; agriculture, forestry and land use; and the built environment. As the main drivers of global emissions, these sectors have the potential to create change at scale and therefore offer opportunities for technology to help achieve a transition to a low-carbon economy.

We examined each of these sectors and, based on current information, suggest possible applications of 4IR technologies in each, with a focus on potential emissions reductions. As discussed, our analysis focuses on the application of emerging technologies for climate change mitigation, although applications relating to adaptation are noted at the end. Additional research will be necessary to estimate cost curves, calculate potential emissions-reduction benefits, and determine the applicability of relevant technologies, or combinations of technologies, as well as their strategic deployment, timing and sequencing.

Table 1 presents the emerging 4IR applications, by sector, that are likely to become available for use in developing countries in the near term (up to 2020) and medium term (2020–2030).

In the near-term examples, we included applications that already exist and/or are in use in developed countries. Then, we considered the necessary infrastructure required for scaling these, with smaller-scale or modular options more likely to be available in the near term and therefore more likely to provide opportunities to leapfrog preconceived routes to economic growth and development.

For the medium term, we used these two criteria to assess our knowledge and understanding of broader 4IR applications that are in development or at the early stages of deployment. In the section on ‘Maximising the opportunities’, we provide an initial discussion of the technical and quantitative considerations needed for policy development and technology deployment, including the extent to which developing countries can be ‘first movers’ or ‘fast followers’ in these technologies (i.e. rapidly follow patterns of adoption in more advanced economies).

**Table 1. Examples of emerging 4IR applications in developing countries**

Sector	Near term (2017–2020)	Medium term (2020–2030)
Energy	<ul style="list-style-type: none"> <li>Blockchain (e.g. wholesale and peer-to-peer energy trading)</li> <li>Artificial intelligence (e.g. smart meters, energy efficiency, demand- and supply-side management)</li> <li>Solar roof tiles</li> </ul>	<ul style="list-style-type: none"> <li>Internet of things (e.g. sensor-based grid management)</li> <li>Solar sprays to increase the generation capacity of surfaces</li> <li>Advanced battery storage</li> <li>Heatless production in power plants</li> </ul>
Transport	<ul style="list-style-type: none"> <li>Electric vehicles, charging and associated storage networks</li> <li>Real-time traffic management</li> <li>Cloud-based technology and the Internet of things for efficient transport networks</li> </ul>	<ul style="list-style-type: none"> <li>Autonomous (electric) vehicles and ‘transportation as a service’</li> <li>Cloud-enabled communications between vehicles and infrastructure</li> <li>Synthetic biofuels</li> </ul>
Production and consumption	<ul style="list-style-type: none"> <li>Robot-assisted manufacturing and delivery</li> <li>3D printing (individual components)</li> <li>Synthetic biology for waste management</li> </ul>	<ul style="list-style-type: none"> <li>3D printing (decentralised manufacturing)</li> <li>Internet of things in industrial processes</li> </ul>
Agriculture, forestry and land use	<ul style="list-style-type: none"> <li>Nano-satellites and drones for remote sensing</li> <li>Blockchain-enabled land registries</li> <li>Sensor-based networks for real-time agricultural monitoring</li> </ul>	<ul style="list-style-type: none"> <li>Blockchain/Internet of things supply chain transparency</li> <li>Blockchain-enabled land and property transactions</li> </ul>
Built environment	<ul style="list-style-type: none"> <li>Internet of things-enabled energy efficiency</li> <li>Artificial intelligence-enhanced building design</li> <li>Internet of things- and artificial intelligence-enabled flood and heat monitoring</li> </ul>	<ul style="list-style-type: none"> <li>3D-printed building materials</li> <li>Internet of things- and blockchain-compatible smart cities</li> </ul>

Sources: PwC *Innovation for the Earth* and authors’ analysis

Our analysis only considers 4IR technologies and applications that are perceived as being available now or in the near future. As the 4IR evolves, there may well be technologies and applications that are currently 'unknown unknowns' but have the potential to offer a step change in emissions reductions, or other paradigm shifts. It will be important, therefore, to assess and monitor not only the costs and applicability of current technologies, but also new options and opportunities as they appear on the horizon.

## Energy

Electricity and heat production contribute 25% of greenhouse gas emissions,<sup>54</sup> and new technologies in this sector are central to achieving decarbonisation and electrification targets (e.g. more powerful and efficient solar cells) and achieving a low-carbon energy future. In terms of finance, it is forecast that approximately US\$20 trillion in investment will be required by 2040 to achieve global low-carbon ambitions in the energy sector.<sup>55</sup> These include clean energy, which was included in approximately 80% of the NDCs submitted to the UNFCCC.<sup>56</sup>

The six NDCs reviewed for this study shared several actions towards achieving low-carbon energy ambitions. We describe these actions and highlight some emerging technological applications that could help to meet goals and reduce emissions in the energy sector.

**Diversify to include a larger share of renewables in the energy mix.** All six NDCs highlighted the increasing importance of renewables, although countries differed in their targeted mix of renewable sources. Colombia, Ethiopia and Kenya focus on increasing the overall share of domestic renewables in the energy mix. Bangladesh and India set targets for increasing the capacity of renewables generation as part of a wider increase in energy system capacity, but will retain a significant proportion of energy from coal.

Emerging artificial intelligence technologies will enable the energy industry to diversify by uncovering currently unknown patterns in demand and supply. This will allow for better monitoring and response to energy demand: demand will be more predictable and the energy industry more efficient in its supply. Renewables generation will be able to take advantage of this, particularly as advanced battery storage using advanced materials will reduce intermittency issues and improve load factors. This shift to renewables can be encouraged, for example with supportive NDC policies, to provide a greater incentive to invest in renewables, bolstering the private sector's provision of renewables over traditional fossil-fuel energy, and broadening the range of low-carbon options. And, as prices for battery storage continue to drop, renewables will be increasingly able to support grid stability and provide low-cost, low-emissions energy, as renewable electricity can be stored for later release into the grid.

**Increase investment in renewables.** To reduce emissions from the energy sector, generation capacity from renewable sources will need to increase substantially. Solar and wind were the most frequently cited potential sources of renewable energy in the six countries' NDCs, and were identified as key areas for future investment. The exponential increase in the deployment of solar and wind technology, and their potential for decentralised energy provision, particularly in Africa and Asia, offers significant scope for the large-scale roll-out of these technologies to remote communities. This will improve energy access in developing countries, which is consistent with broader development goals.

Costs of renewables have fallen dramatically and will continue to fall due to continued technological progress and increasing deployment and scale. Investments in wind and solar PV technologies are becoming more attractive as their potential applications and geographic scope increase, and new sources of financing become available in developing economies. In view of Paris Agreement commitments and future carbon scenarios, development banks are setting up new funds for renewables investment, and private firms are engaging with these.<sup>57</sup>

Emerging 4IR technologies could accelerate and enhance solar and wind deployment, for example through peer-to-peer energy trading that uses blockchain technology to allow off-grid energy generation through decentralised payment systems (see Box 4).<sup>58</sup> These technologies will facilitate a shift in business and delivery models from integrated, state-owned and/or state-operated utilities to a consumer-driven, highly competitive market. Meanwhile advanced materials, artificial intelligence and big data will continue to improve technology performance and system integration, increase the ability to connect

people currently outside the system, drive down operating costs, boost maintenance predictability and improve grid stability.

**Improve energy efficiency (production).** Not all countries envisage a significant shift in their energy mix, even amid broader economic shifts. Energy systems that expect to continue to rely on coal and other fossil fuels may hope to mitigate some of the associated pollution. Much of the focus is on increasing coal efficiency, which can be achieved by phasing out the least efficient coal power plants and developing high-efficiency, low-emission coal-fired power plants.<sup>62</sup> These can help to fill the energy gap in countries unable to transition to renewables due to feasibility or investment barriers. Advanced materials, which reduce heat loss, could further increase the efficiency of fossil-fuel energy plants.

**Improve energy efficiency (use).** Many developing countries currently have low per capita energy use, but this is expected to increase dramatically in a business-as-usual scenario, as prosperity and connectivity to the energy grid increase. Most of the six NDCs cite increased energy efficiency as an important target, with India detailing several ongoing programmes such as the use of compact fluorescent lamps and light-emitting diodes (commonly known as LEDs) to increase lighting efficiency.

As the technology develops, other technologies will provide further efficiency gains. For example, solar sprays can be used to coat surfaces (e.g. cars and buildings) to turn these into solar cells and thus enable clean energy generation. This will increase energy efficiency, with energy production offsetting the energy used by these objects.

**Increase energy access.** Globally, an estimated 1.06 billion people lack access to electricity,<sup>63</sup> and three of the NDCs analysed cited this as a significant challenge. Increasing access is not only the responsibility of the public sector, but an opportunity for private investment. This is leading to private sector activity in Africa and South-East Asia in particular, where start-ups and small and medium enterprises, such as Off-Grid Electric and Sunlabob,<sup>64</sup> are using new business models to deliver small-scale, off-grid energy access.

Secure, accessible energy supplies, as well as cleaner sources, are key to creating a more sustainable, low-carbon energy future. Off-grid electricity is a growing market segment and represents an important part of the future energy sector. Emerging and exponential technologies can disrupt the traditional, centralised electricity industry, facilitating and creating incentives for the private sector to provide access to previously underserved markets. Micro-generated grids, enabled by technologies such as advanced materials for battery storage, 3D-printed solar cells and solar sprays, and pay-as-you-go services for off-grid supplies (see Box 4) will all support this. Meanwhile, the Internet of things and artificial intelligence will remove the need to be connected to traditional grid infrastructure, which has long been a barrier to wider, more comprehensive electricity access.

In addition, the falling costs of renewable energy offer hope for increasing the energy supply in developing countries. A major issue, which has been extensively studied, is how technologies disrupt

#### Box 4. The 4IR in action: Peer-to-peer energy trading in India

Access to electricity in rural India was only 70% in 2014,<sup>59</sup> while poor and rural households spend a higher proportion of their income on energy than wealthier ones, typically 5–20%.<sup>60</sup> In addition, much of the rural population has no access to banking services, making bank-based payment methods difficult.<sup>61</sup>

In response, two companies have combined their expertise to increase energy access and provide a suitable payment mechanism for those not connected to the energy grid. Veriown is developing solar home systems (off-grid solar power-generating units that provide households with energy), for which Wattcoin Labs, a US-based start-up, is using blockchain technology to create a digital currency that allows payments to be made. This currency enables local vendors with smartphones to sell credits on a smart payment card which, when placed on a reader on the solar home system, converts the credits into electricity.

This system provides rural people with electricity without the need for bank-based payments or being connected to the national electricity grid. The companies' long-term goal is to allow users to trade electricity and carbon value at a micro scale, by selling any excess energy generated by their home systems.

local power relations, such as those involving centralised utilities which provide power at subsidised rates and political groups that benefit from the provision of these services.<sup>65</sup> New technologies could be beneficial here; for example, biometric identification and mobile phone-based cash transfers could enable more targeted and more efficient subsidy targeting, leading to a more extensive and inclusive energy economy.

### Transport

The transport sector accounts for nearly 15% of global emissions<sup>66</sup> and just over 50% of global oil demand.<sup>67</sup> Switching to low-carbon alternatives will be central to achieving NDC targets and limiting global temperature increases. The NDCs we surveyed set out a range of actions towards this, from cleaner fuels to more efficient urban transport systems.

**Electric and autonomous vehicles.** In 2015, Bangladesh and India, alongside Bhutan and Nepal, entered into a Motor Vehicle Agreement. Part of this is the promotion of environmentally sustainable transport.<sup>68</sup> In a separate initiative, India recently unveiled plans to take petrol and diesel cars off the road (see Box 5); by 2030, all cars sold in India are expected to be electric (although this announcement came after its NDC was submitted).<sup>69</sup>

The transition to electric vehicles, alongside a shift from fossil fuel-generated power to renewable energy for charging these, is likely to play a key role in enabling low-carbon transport and reducing emissions, particularly in congested urban areas. This could be furthered through the use of autonomous electric vehicles. Self-driving cars will enable ‘transportation as a service’ to grow,<sup>70</sup> dramatically reducing the need for car ownership and potentially reducing the number of vehicles on the road. This will help to make transport systems more efficient overall, for example reducing the need for parking spaces and opening up new possibilities for urban design.<sup>71</sup>

**Cleaner fuels.** Of the six NDCs reviewed, India’s and Indonesia’s specifically mention increasing the use of biofuels and biofuel blends in their transport sectors, while Ethiopia’s covers more general concepts, including investing in transport systems that use clean, renewable energy. The growth of the biofuel market, and the development of vehicles and systems that can use biofuels at scale, mean that cleaner fuels are becoming a more feasible and cost-effective way to reduce emissions in the transport sector.<sup>74</sup> Deploying appropriate mechanisms to roll out this infrastructure and technology will require additional investment and buy-in from large transport providers (e.g. logistics and distribution companies) as well as public sector transport bodies.

Biofuels will not only become more efficient in use, but also in production. Research into synthetic biology and advanced materials for biofuel production has the potential to reduce problems associated with the use of extensive areas of cropland for biofuel production. Without these land constraints, it should become possible to produce biofuels at greater scales, improving their cost-competitiveness. This would make biofuels a more feasible and attractive alternative to fossil fuels, in the transport sector and beyond.

### Box 5. The 4IR in action: Electric vehicle commitments in India

Air pollution is a significant threat to the health of India’s population and its potential economic growth. The World Bank estimates that air pollution cost India approximately US\$560 billion in 2013, in terms of welfare losses and foregone labour output, and kills over one million Indians every year;<sup>72</sup> other studies draw similar or worse conclusions.<sup>73</sup>

Transport emissions are a key source of air pollution, and in 2017, the Government of India announced that every car sold in India from 2030 will be electric. India’s energy minister, Piyush Goyal, said the government will financially support the initiative for the first two to three years of implementation; after this, the economic costs of electric vehicles will potentially be low enough that the market will be “driven by demand, and not subsidy”. Similar announcements to phase out fossil fuel-reliant vehicles over the coming decades have since been made by France, Norway, the UK and other countries.

**Technology-enabled transport.** In the six NDCs reviewed, opportunities for reducing the transport sector's carbon footprint included the use of technology to enhance the impact of new transport developments, in areas such as infrastructure investment and urban transformation,<sup>75</sup> and especially smarter, low-carbon urban transport systems (e.g. electric bus networks and smart traffic-reduction schemes). For example, using sensor-based, real-time traffic flow-management systems, enabled by the Internet of things, could redirect and control traffic in urban areas more effectively, reducing congestion and pollution. It could also minimise fuel use by public transport by identifying inefficient routes. Moreover, cloud technologies will be able to communicate information between vehicles and transport infrastructure (e.g. traffic lights) to optimise traffic flows and increase overall efficiency.

**Shift to rail.** Investment in a shift from road to rail, particularly for long-haul transport, was highlighted in half of the NDCs analysed, and some initiatives are already under way. India is building 'dedicated freight corridors' on the railway system which are expected to save about 457 million tonnes of CO<sub>2</sub> over 30 years.<sup>76</sup> Nationwide initiatives, backed by the public sector, development banks and donor agencies, can drive such large-scale shifts and create demonstration projects for a broader shift in the way rail and transport projects are undertaken. And, where there is an investment gap, efficiencies gained through the use of 4IR technologies (e.g. to inform smarter project planning and development) may make investments in rail projects more attractive to the private sector.

Smarter project planning and development could include the use of autonomous vehicles (e.g. driverless trains) to reduce operating costs and accident rates. The Internet of things and artificial intelligence could enable real-time project development updates, reducing inefficiencies and decreasing potential delays due to poor planning. These 4IR applications are also likely to improve the efficiency of rail operations, reducing emissions and the overall cost of the project – thereby providing a better return on investments.

**Efficient urban transport.** India's NDC sets out a vision of urban transport that moves people rather than vehicles, in which mass rapid transport systems play an important role; Bangladesh's NDC states a similar aim. Both set out a new urban environment in which transport systems are clean, and transport and fuel efficiencies increase.

Facilitating communication links between different mass transport systems, using cloud technologies and the Internet of things, could speed up the establishment of an efficient transport network and, once in place, reduce delays, improve efficiencies and reduce emissions. Diffusion at scale of transportation as a service, enabled by a host of 4IR technologies, could also significantly increase the efficiency of urban transport, assuming policy support is in place.

### Production and consumption

Industry produces just over 20% of global greenhouse gas emissions.<sup>77</sup> This significant footprint could be mitigated by 'circular economy' opportunities (see Box 6), which could add up to US\$1 trillion to the global economy by 2025.<sup>78</sup> Sustainable production and consumption is a cross-cutting theme, addressing issues from recycling to production efficiencies, and featured, to some extent, in all six NDCs, which set out a range of possible actions.

**Increase efficiency.** Four of the NDCs address the need to improve the efficiency of goods production. Mechanisms to achieve this range from enhanced action for energy efficiency to energy-efficiency trading schemes, such as the Perform Achieve and Trade scheme in India.<sup>83</sup>

The range of ambitions set out reflects the technological and industrial requirements needed for energy efficiency to move from theory to implementation. In India, there is an opportunity to redevelop pre-existing industry to be more energy efficient, and its NDC outlines several opportunities and ambitions. Elsewhere, embedding energy efficiency in regulation and policy, and offering low-cost technologies that enable change, could speed up the implementation of energy efficiency in underdeveloped markets where industries are still taking shape.

The deployment of robots will enable more efficient industrial production systems in the future, which optimise the use of raw materials in production processes, as well as utilities such as gas and electricity. Factories set up in developing countries through foreign direct investment by multinational companies

### Box 6. The 4IR in action: The circular economy in Dar es Salaam

Every day in Dar es Salaam, over 400 tonnes of plastic waste are not recycled or collected.<sup>79</sup> Meanwhile, the unemployment rate stood at 21% in 2015,<sup>80</sup> with youth employment in particular a national priority.<sup>81</sup> The circular economy offers a way to help address both these problems. ReFab Dar<sup>82</sup> is an experimental project which tests the feasibility and scalability of turning plastic waste into filaments that can be sold abroad and converted into products for local communities. If successful, this will offer new livelihood options for local youths and increase their prosperity. It will also mean that plastic bottles are used to create filaments and 3D printed products, rather than polluting the environment.

are likely to deploy robot technologies, without the need for public sector investment. In addition, 3D printing will enable the localised production of global designs, reducing transport costs, distribution needs, and waste and packaging. Packaging may also become cheaper to produce, as biomass-based alternatives to plastic will be less energy- and resource-intensive.

**Waste management.** The need to improve waste management is an ever-present and growing issue in many developing countries, particularly in urban areas. Although it is referenced in many NDCs, including those from Bangladesh, Colombia and India, the documents provide limited details on sector-based plans. There are technology-based solutions available, however.

The 'industrial Internet of things', which combines smart machines, smart materials and smart products across industrial value chains, has the potential to optimise resource consumption and reduce waste. Adapting this to developing country contexts will be challenging, though. Policies will need to support the implementation of such systems.

**Waste to energy.** Converting waste into energy is an opportunity for developing countries and is a stated aim across the NDCs surveyed. In India, for example, the potential for waste-to-energy generation in urban areas is 439 megawatts of power annually. This would remove 62 million tonnes of waste from cities and save the equivalent of 1,240 hectares of landfill each year.<sup>84</sup>

Existing options include biomass-based thermal energy generation from organic waste by-products and landfill gas capture. Emerging technologies, including biothermal energy capture and storage, are expected to increase in efficiency significantly and improve the effectiveness of waste-to-energy conversions.

**Rational use of ecosystem services.** Policies for this ambition are being developed in some countries, notably Colombia, which plans to encourage the better management and efficient use of resources such as water. However, there is the potential for enhanced knowledge-sharing about resource use, through a sensor-based network facilitated by the Internet of things and cloud technology. This should enhance resource allocation and reduce inefficiencies in resource value chains and economies, thereby contributing to emissions reductions.

**Sustainable consumption.** This did not feature in many of the NDCs reviewed, although Indonesia's NDC discusses implementing sustainable production and consumption patterns with the aim of reducing landfill through the 'three Rs' – reduce, reuse, recycle. Shifts in consumer behaviour such as this are often difficult to achieve, but can drive significant changes in emissions patterns by making businesses more accountable for their emissions. Intelligent packaging and optimised product design, both facilitated by 3D printing, have the potential to drive such a transformation in consumption patterns.

#### Agriculture, forestry and land use

The agriculture, forestry and other land-use sectors account for close to 25% of global greenhouse gas emissions.<sup>85</sup> The growth in the global population means that food production will need to increase over the coming decades. This is also a sector at risk from the impacts of climate change.<sup>86</sup> In addition, it provides a significant proportion of many developing countries' economies. Achieving climate resilience in this sector is therefore a priority for many developing countries.

More encouragingly, agriculture- and forest-based economies, which tend to have a small industrial base and a dependence on biomass for energy, offer great potential to reduce greenhouse gas emissions. In Kenya, for example, 75% of emissions were derived from the sector in 2010,<sup>87</sup> offering considerable scope for reductions. Globally, 80% of the NDCs mention mitigation in the agricultural sector, while 27% list REDD+<sup>88</sup> as an option.<sup>89</sup>

Emerging and exponential technologies have a potentially transformative role to play in the transition of these sectors, from the use of drones to assess crop land and monitor weather conditions, to using the Internet of things to relay information about global crop prices and optimise planting schedules. Adapting these technologies so that they are accessible to smallholder farmers in developing countries will be central to their success in contributing to successfully implementing the NDCs.

Broadly, actions in these sectors fall under more sustainable land use, and this was a key theme across all six NDCs reviewed, with several ambitions and actions included.

**Afforestation.** Reducing deforestation and afforesting degraded and deforested land were frequently mentioned in the NDCs analysed. All six countries are UN-REDD partner countries, and three of the NDCs explicitly mentioned REDD+ implementation as an action.

The exchange of data on deforestation is already being supported by data-visualisation tools such as Trase, and this is beginning to drive accountability in global supply chains.<sup>90</sup> The Internet of things will enable enhanced data tracking throughout supply chains, resulting in greater transparency; this should lead to more demanding reporting requirements from multinationals, and has the potential to reduce large-scale deforestation.

**Tracking and measuring.** Emissions from the agriculture, forestry and land-use sectors are complex to track and monitor. Bangladesh, for example, did not include emissions from these sectors in its country-level emissions model, due to the difficulties in obtaining the necessary data. These emissions have been included in the models of other countries surveyed; Colombia also noted plans to obtain better data. This could be achieved through nano-satellites, such as those launched by Planet, a California-based start-up, as well as drones. These technologies provide the opportunity for the real-time remote sensing of deforestation and land-use change across large and/or remote areas. Potential uses include the better monitoring of protected areas for illegal activity.<sup>91</sup>

**Smarter agriculture.** Climate-smart agriculture aims to tackle productivity and income challenges for farmers while addressing climate change resilience and emissions reductions.<sup>92</sup> Although Kenya was the only country to reference climate-smart agriculture in its NDC, other countries cited the need for more sustainable agricultural development, as well as the need to increase agricultural productivity. For example, Bangladesh's NDC mentions increased mechanisation in agriculture, which will lead to fewer draft cattle and thus lower methane emissions.

Potential opportunities to embed 4IR technologies in climate-smart agriculture include the use of sensor networks to collect highly localised, real-time data on temperature, humidity, light, pressure and soil moisture to improve farming strategies, and the use of blockchain-enabled payments to offer subsidies directly to farmers, instead of cash payments. Drones could also play an increasing role (see Box 7). However, as climate-smart agricultural practices develop, countries will need guidance around the use of these emerging and exponential 4IR technologies.

### Built environment

Cities account for up to 70% of global emissions and use over two thirds of the world's energy,<sup>95</sup> and several of the sectors discussed earlier come into play in the context of the built environment. With the proportion of the world's population living in urban areas expected to rise to 60% by 2030, and the number of city residents increasing by half a million each week, urban emissions will continue to increase – unless significant changes are made to the built environment and the ways in which cities consume resources.<sup>96</sup> Emerging and exponential technologies can help accelerate and achieve NDC ambitions in this sector, while also making cities and homes more sustainable.

### Box 7. The 4IR in action for adaptation: Using drones to help farmers in the Philippines prepare for climate disasters

The Philippines is among the countries most at risk from tropical storms and other natural disasters.<sup>93</sup> In 2013, Typhoon Haiyan devastated 600,000 hectares of farmland and caused damage costing the agriculture sector over US\$700 million. Farmers also face increasingly uncertain risks due to climate change.

The Government of the Philippines and the Food and Agriculture Organization of the United Nations (FAO) have conducted a pilot programme to help farmers prepare for climate disasters using drones. The unmanned aerial drones, which can cover 600 hectares a day, are equipped with navigation and photogrammetric equipment that can generate detailed, data-rich maps from aerial photographs. Once analysed, the data gathered can be used to identify which agricultural systems are at the greatest risk from natural disasters, and identify how these risks can be countered (e.g. through contouring, building retaining walls or planting protective vegetation).

The drones can assess immediate risks days before a predicted storm reaches land, enabling more timely responses. In addition, they can provide more consistent and more accurate data than collated local responses, helping planners to identify the most appropriate interventions.<sup>94</sup>

**Improved transport efficiency.** Public transport in developing countries, both within and between cities, is often limited and of low quality, increasing inefficiencies in the sector.<sup>97</sup> The NDCs from Bangladesh and India both discuss plans for mass rapid transit systems in cities, with a focus on moving people as efficiently as possible. Meanwhile, systems such as the Bus Rapid Transit system in Bogota, Colombia, offer the opportunity to reduce urban congestion, as well as emissions, through lower-emission, higher-passenger-volume vehicles.<sup>98</sup>

Smart urban mobility could also be achieved through autonomous electric vehicles, transportation as a service, and the Internet of things when linked to cloud technology. These technologies have the potential to transform cities' transport networks. For example, radically improved urban design, enabled using a combination of these technologies, can optimise traffic flows, minimise parking needs and reduce air and noise pollution, particularly when automated electric vehicles become the dominant form of transport.<sup>99</sup>

**Energy efficiency in buildings.** Cities in developing countries are expected to experience some of the fastest rates of population growth in the coming years; making new buildings energy efficient will reduce their emissions profiles and enhance countries' ability to meet their NDC goals.<sup>100</sup> Half of the NDCs reviewed discuss increasing the energy efficiency of cities, particularly buildings, through better heat insulation and cooling methods and new minimum energy standards, with similar initiatives for industry and transport. One option is 3D printing, which could enable the mass production of energy-efficient homes. In addition, artificial intelligence-enabled building design will use machine learning to continually optimise building efficiency and increase material efficiency in construction and energy in use.

**Smart cities.** India's NDC sets out its desire to create smart cities, with 100 initially planned (this has since been raised to 109), and smart renewal plans for 500 others (see Box 8). Other countries make less explicit references to this concept, but include actions that will contribute towards similar results. Many 4IR technologies can facilitate smarter urban systems (e.g. for mobility, energy, water and waste), with significant potential for emissions reductions, for example through improved efficiency, reduced waste and maximised performance.

#### Adaptation and the 4IR

Adaptation remains a critical concern for many developing countries, and its importance is reflected in a wide range of NDCs. This paper focuses on the contribution of new technologies to mitigation and low-carbon development, and we have therefore not analysed potential 4IR applications to adaptation goals comprehensively. Nonetheless, we have come across several illustrative examples during our research.

**Widespread use of the Internet of things.** Networks of low-cost sensors, connected through the Internet of things, have the potential to increase the speed and effectiveness of monitoring and

### Box 8. The 4IR in action: India's Smart Cities Mission

India's urban population is expected to grow from 400 million people in 2014 to 650 million by 2034.<sup>101</sup> In response to this explosive growth, the Government of India has set out its Smart Cities Mission to redevelop 100 cities into advanced, sustainable and population-friendly cities. These smart cities will be sustainable in several ways. Smart transportation has a large role to play, with an extensive network of electric vehicle-charging stations and the development of next-generation rechargeable batteries expected to enable a transition away from fossil fuel-powered transport. Smart buildings will also contribute, saving up to 30% on water usage and 40% on energy usage, and reducing building maintenance costs by 10–30%.<sup>102</sup>

management processes, and enable more rapid responses. This is already happening in a range of adaptation contexts.<sup>103</sup>

- **Automated insurance claims for farmers.** Syngenta has deployed connected micro-weather stations through its 'Kilimo Salama' (Safe Farming) project. These monitor temperature and moisture in the air and soil, solar radiation, wind speed, air pressure and other factors, then transmit the information to insurance firms, which plug the data into digital models that estimate losses after weather events. The insurance firms make mobile payments to farmers based on these models, automating and speeding up the insurance claims process.
- **Using the Internet of things to monitor water and irrigation.** In India, 20,000 smallholder farmers use Nano Ganesh, a mobile phone-operated unit that attaches to the pumps of their drip irrigation systems. An actuator operated by the phone turns the pump on and off, and the farmer can see if the pump is receiving electricity and if water is available.

**Using drones to address climate change in the Maldives.** With 80% of its islands only 1 metre above sea level, rising sea levels represent a significant threat to the Maldives. It is important, therefore, for local policy-makers to understand the physical vulnerability of each island, to aid decision-making. Up-to-date and regular mapping is a momentous challenge, however; it is estimated that mapping just 11 islands using conventional methods would take almost a year, meaning the timely mapping of areas before and after disasters is extremely difficult.

The United Nations Development Programme has piloted the use of drones to make mapping more efficient. In just one day, a drone developed a 3D map of Mahibadhoo, a village severely affected by the 2004 tsunami. This helped to identify safe areas in case of floods, and demonstrated how the local landscape had changed. In future, drones could support search-and-rescue missions, providing live images of hard-to-access locations.<sup>104</sup>

## Country examples: 4IR challenges and opportunities for Bangladesh and Kenya

CDKN has been closely involved in developing the NDCs for Bangladesh and Kenya, and is currently helping both countries to deliver on their climate commitments. Drawing on this experience, we highlight some of the 4IR challenges and opportunities facing these countries as they develop sector-level plans and implementation strategies.

### Bangladesh

#### *Creating the NDC and sector plans*

CDKN supported the development of Bangladesh's NDC, as well as the three detailed sector plans which sit beneath it, covering power (i.e. energy), industry and transport. These outline specific actions to achieve the ambitions set out in the NDC. While these sectors are some of the largest sources of emissions, they do not cover all potential actions and sectors in the NDC. Bangladesh has also developed an Implementation Roadmap, outlining the steps needed to integrate NDC implementation into its Climate Change Strategy and Action Plan, and its Seventh Five-Year Plan.



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#### *How the 4IR could help*

Awareness of emerging technologies within the government is low, and the 4IR is not yet being considered in NDC implementation plans. However, sectoral plans cover the periods 2016–2019 and 2020–2025; the next draft of the 2020–2025 plan presents an opportunity to follow this study's 'Roadmap to 4IR planning and implementation' (see Figure 3 in Conclusions and recommendations). Bangladesh is currently producing its Eighth Five-Year Plan, which is due to commence in 2021 and hence correspond with the sectoral plans. If discussions around emerging technologies are included now, it could help catalyse future developments involving exponential technologies.

In discussion with the CDKN country team, it has been suggested that Bangladesh's garment industry could benefit from 4IR advances, given its extensive use of energy-inefficient technologies, but further consultation and exploration are required to determine which 4IR-enabled technologies are applicable, and in which areas. Exploring opportunities in the garment industry may shine a light on potential synergies with other sectors.

#### *Barriers*

The Government of Bangladesh's capacity to deploy and embed emerging technologies may need to be strengthened to raise awareness of them and enable a fuller consideration of their potential. It is important that where new technologies become available and cost-effective, their potential usefulness and how they could be integrated into sector action plans are explored and explained.

Another barrier is the uncertainty regarding the absolute and relative costs of new technologies. In the absence of detailed costings, the private sector is likely to be cautious about investment due to the perceived high costs of 'frontier' technologies (although these typically appeal to early adopters willing to pay high prices). Cost barriers are compounded by the difficulties that most companies have in breaking into high-tech areas. Strong support for businesses may therefore be required.

It takes time to build institutional frameworks and capacity, which can result in slow uptake of new technology. If the benefits can be demonstrated, however, then political will should increasingly embrace new technologies. The UNFCCC Technology Transfer Framework<sup>105</sup> could be a helpful entry point for developing countries such as Bangladesh to gain an initial footing with 4IR technologies, through its focus on needs assessment, information, enabling environments, capacity-building and mechanisms for transfer.

## Kenya

### *Creating the NDC*

The Ministry of Environment and Natural Resources prepared Kenya's NDC, with technical assistance and stakeholder engagement support from CDKN. All Kenyan ministries were notified during the preparation process, although limited time resulted in most of the analysis in the NDC being taken from Kenya's Second National Communication,<sup>106</sup> with only an aggregated emissions-reduction target being included.



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This overarching target is now being broken down into sectoral targets, incorporating a wide range of stakeholders at both national and subnational levels. For example, electricity-generating companies are involved in energy sector discussions, alongside the Ministry of Energy.

### *How the 4IR could help*

CDKN has found that 4IR technologies are rarely, if at all, considered when drawing up sector plans, or in NDC implementation. This is despite Kenya having prominent examples of technological innovation, such as the widespread M-Pesa mobile payment system, while IBM and the Kenya Climate Innovation Center have set up research and innovation labs, respectively. Examples of 4IR technologies currently in use in Kenya, and aligned to Kenya's NDC, include:

- real-time traffic monitoring to improve Nairobi's transport system
- solar roof tiles in rural areas<sup>107, 108</sup>
- temperature and humidity monitoring, and smart metering for water use, in greenhouses and drip irrigation systems.

Further technologies are currently being considered and debated more widely in information and communications technology (ICT) and public policy circles, including blockchain technology, cloud technology and autonomous vehicles. We have identified other areas where 4IR technologies might be applicable. For example, autonomous vehicles (e.g. drones, driverless tractors) could make farming less labour-intensive, while the Internet of things could be used to share climate information among remote smallholder farmers. In forestry, the System for Land-based Emissions Estimation in Kenya (SLEEK) combines data from geographic information systems with data from the ground to calculate emissions; there is an opportunity here to use cloud technology to give real-time updates and allow remote monitoring of land-use emissions. In industry, there is an opportunity to increase efficiency through robotics and machine learning.

### *Barriers*

The private sector, particularly IT companies and venture capitalists, is more likely than the public sector to be the source of new technological developments and to provide emerging technology financing. However, the regulatory landscape around these technologies remains uncertain; the government will need to reform policies substantially to incentivise significant levels of investment. In this respect, it will be useful to draw on the process of developing M-Pesa. This was led by the private sector and brought together diverse stakeholders, resulting in significant changes to regulations by the government which provided the necessary safeguards to the public.

Equity and social inclusion will remain a challenge. Experience in Kenya has shown that the uptake of a range of technologies is more rapid in urban areas than rural ones. In addition, the effect of

emerging technologies on jobs is still uncertain. Due care must be taken to guide technology development towards a pro-poor, inclusive path. Moreover, it will be essential to encourage the local development and deployment of technologies, rather than importing them wholesale. This could be supported by developing the skills of the labour force, for example through improved curricula in technical institutes and through innovation labs. Strategies and methods for this will need to be tailored to the varied and widespread needs of both individuals and technologies, and may require skills beyond those purely focused on the technologies themselves (e.g. marketing and business development).

There is a risk that implementing these technologies becomes the focus of the Ministry of Environment and Natural Resources. For pro-growth, inclusive and sustainable outcomes, a cross-sector and pan-government approach is needed, drawing in, among others, the Ministry of Information, Communications and Technology, the National Treasury and the Ministry of Devolution and Planning. This should be coupled with active engagement and partnerships with the business and investment community. This multi-stakeholder approach will also help to ensure alignment with the Sustainable Development Goals.<sup>109</sup>

In both Kenya and Bangladesh, inclusive governance of 4IR planning will need to become a priority, with a wide range of stakeholders involved. In Kenya, this can still be coordinated through the Ministry of Environment and Natural Resources if the intention is to address mitigation. However, if other primary objectives are sought, then it may be more appropriate if, for example, the Ministry of Industry was to lead a coordinated 4IR policy response.

### Emerging risks from emerging technologies

Alongside the risks that arise from any technological investment and deployment (e.g. operational, delivery and performance risks), it is hard to ignore the broader – and more significant – societal consequences that the development and utilisation of 4IR technologies could create. From the impacts of automation on jobs, to data privacy, cyber security and biotechnology ‘bio-errors’,<sup>110</sup> governments and businesses have important roles to play in ensuring technology supports a broad range of societal wants and needs.

We have not conducted a comprehensive analysis of the potential negative impacts of 4IR technologies but, based on our discussions with country practitioners, we share some illustrative examples which demonstrate the need for governments and businesses to develop responsible technological governance structures.

#### Issues specific to developing countries

Developing countries are likely to face a range of challenges over and above developed country concerns. For example, many have a much larger proportion of young people due to enter the workforce in the coming years. They must also prepare for the 4IR’s implementation in developed countries, which may be relatively more attractive for global investment capital.<sup>111</sup>

Mainstreaming the development and local adaptation of 4IR technologies will require knowledge, technological capability and investment. This is lacking in many developing countries; building the capacity of local businesses is needed to ensure they do not become over-reliant on foreign products and services, but develop and adapt their own technologies.<sup>112</sup> This will require policy-makers, donors and other stakeholders to distinguish between innovations reliant on imported technologies and those manufactured, assembled or developed locally.

Developing countries cannot afford to wait and see how the 4IR evolves in developed countries, or how advanced economies solve the resulting problems. Identifying long-term ‘no-regrets’ investments – in their skills base, institutional capacity, investment environment and technology innovation systems – can lay the foundation for future 4IR investments. Regardless of whether countries have prepared to implement the 4IR, all are likely to begin to feel the impacts on similar timescales. As a result, developing countries will want to be at the forefront of designing and piloting solutions to potential issues arising from the 4IR.

### Inclusive economic development

Economic growth and development are priorities for any country. Climate goals must therefore link to and support plans to boost economic growth. This is especially true for developing countries, where eliminating poverty through inclusive economic development is often the top priority.

The 4IR will present many opportunities to achieve inclusive, fast-paced growth, through enabling the cheaper and faster creation of new technologies and innovation. These will increasingly allow developing countries to compete more effectively with advanced economies across the digitally-enabled global economy.

Significant threats exist, however, which cannot be ignored. The rise of automation will lead to more efficient production systems, but is also expected to shift dramatically the number and types of jobs available. The role of business and government leaders is to act with foresight and ensure that rising productivity does not decimate overall job numbers. Important questions include:

- How will potential job displacements caused by technology be addressed?
- How do we avoid further rural to urban migration and pressure on developing country cities, as smart agriculture displaces rural jobs?
- Where will the jobs and industries of the future be?
- How can we enable more flexible and sharing-based models?

The consequences of the 4IR for employment, wealth creation and distribution are not yet fully understood and will require further study.<sup>113</sup> Some initiatives are already under way; for example, the International Labour Organization is investigating how to create equitable outcomes in a changing technological landscape and recently announced the Global Commission on the Future of Work.<sup>114</sup>

### Managing energy use

Although the 4IR has the potential to reduce long-term energy demand, it is likely to cause a shift in the type of energy being demanded. Countries will have to prepare for this and adapt. For example, increased adoption of electric cars, and their associated charging ports, will increase loading on electric grids; these will need to become smarter to cope with the additional demand.<sup>115</sup> Enhanced mechanisation of production chains may also increase the demand for electricity.

If not utilised efficiently, it is possible for 4IR technologies to become even more energy intensive than current options. Blockchains provide an example of this, with Bitcoin a useful case study. Bitcoin is built using an energy-inefficient type of blockchain, which has led to its estimated annual electricity consumption of 16.22 terawatt hours – enough to power 1.5 million households in the USA for a year.<sup>116</sup> Alternative implementations of blockchains may reduce energy demands, but this requires the initial designs factoring this in, to avoid these technologies being locked in to inefficient pathways.

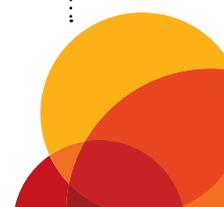
### Retaining effective government controls

The pace of change in the 4IR is one of its defining features, and policy-makers face a challenge to create a regulatory environment that is flexible, adaptable and promotes innovation, while still protecting citizens and principles of justice and fairness. For example, big data, gathered by the Internet of things and processed by cloud computing, could threaten citizens' privacy, while some technologies (e.g. blockchains) have been used to sell illegal goods and defraud investors through 'Initial Coin Offerings'.<sup>117, 118</sup>

Countries should watch other early adopters to understand what lessons can be learned. For example, Vietnam is expected to complete an assessment of cryptocurrencies by the end of 2018, in order to scrutinise and streamline the legal and regulatory framework.<sup>119</sup> This could provide lessons for other countries.

### Intellectual property rights

Over the course of the 4IR, developing countries are increasingly likely to be able to compete in the global marketplace, and individuals able to work more freely across traditional international boundaries.



However, issues such as intellectual property rights and taxation will require close attention to ensure these systems remain fair across countries.

One potential way to help developing countries achieve their ambitions is licensing access to data. Data will become an increasingly valuable commodity, as data-hungry machine learning, the Internet of things and other 4IR technologies gather pace. Traditionally, development efforts have been towards open and transparent access to data, and this still has significant value. Nonetheless, developing countries could take steps to manage the flow of country-specific data, which could be commoditised. This would then incentivise companies and organisations to collaborate with country governments to ensure equitable outcomes.

### **Maximising the opportunities from the 4IR for NDC implementation**

To maximise the potential of the 4IR in terms of achieving climate change goals, NDC planners will need to consider the rapid technological changes that are happening now, and determine whether these are likely to enhance or derail their emissions-reduction goals. As outlined in the Roadmap to 4IR planning and implementation (see Conclusions and recommendations), this involves sharing knowledge about potential 4IR technologies, assessing opportunities for 4IR technologies in the national economy, gaining buy-in from policy-makers and investors for their development and deployment, and incorporating innovation into national planning frameworks.

#### **Technical, financial and quantitative considerations**

Accurate cost curves have not yet been developed for many 4IR technologies. These need to be incorporated into national development and NDC planning. Developing cost curves for new technologies, which can be used in cost-benefit analyses and associated modelling, often presents a challenge, but should increasingly be seen as an opportunity. For example, cost curves will be crucial in fostering a broader acceptance and adoption of emerging technologies among NDC planners. The current absence of agreed cost curves for most 4IR technologies means that cost-benefit analysis is difficult, and leads to a tendency to default to known technology options – but these may be suboptimal in a period of rapid technological change.

Financing – and the views of investors towards the 4IR – will be central to incorporating 4IR technologies in NDC implementation plans successfully. Investors are forward-looking, and tend to embrace investment opportunities in developing countries that are aligned with future technological developments – and where the policy and enabling environments are supportive. Getting these environments right implies giving investors reassurance that they will earn an appropriate risk-adjusted return over their investment time frame. Investors are also likely to favour countries that recognise the potential of 4IR technologies in economic development. Such an open, supportive investment environment will benefit NDC planning and implementation, as private investment will be needed to achieve many climate change goals.

The scale of finance required for new technologies is difficult to estimate with precision. Mobilising private capital may be easier in an enabling environment aligned with 4IR opportunities (i.e. one that includes a supportive regulatory and policy framework) compared to one oriented towards predecessor technologies and potentially encumbered by stranded assets.<sup>120</sup> Moreover, given the requests from developing countries for financial assistance to support their low-carbon transitions under the Paris Agreement, development finance may need to be broadened to support 4IR-focused policies, particularly in developing countries.

Quantitative analysis of 4IR technologies' potential impacts on emissions will be necessary to encourage their broader adoption and strategic use in achieving NDC commitments. In 2015, Swedish technology company Ericsson estimated the impact of different ICTs on greenhouse gas emissions by 2030, across a range of economic sectors including energy, buildings, transport, agriculture, land use and waste. This study estimated that ICTs could reduce emissions by 7–15% compared to a 2030 business-as-usual baseline,<sup>121</sup> although there are high levels of uncertainty around these estimates.

Making estimates of the cost- or emissions-reduction potential of specific 4IR technologies might not be the best way to approach broader systemic change, however, particularly if entire sectors are likely

to be transformed. It is increasingly likely that the rapid pace of change, and the combinations of new technologies that are likely to be deployed, will result not in a future that is a low-carbon version of today's economy, but in a fundamentally different economy – potentially one with a much lower cost and emissions base.

For example, according to a recent study of the economics of autonomous electric vehicles (based on known cost curves and existing business models), “[b]y 2030, within 10 years of regulatory approval of autonomous vehicles, 95% of U.S. passenger miles traveled will be served by on-demand autonomous electric vehicles owned by fleets, not individuals, in a new business model [called] ‘transport-as-a-service.’”<sup>122</sup> The study forecasts 18% higher electricity demand overall, but energy demand for transportation that is 80% lower, and that overall CO<sub>2</sub> emissions from light-duty vehicles will fall by 90%.<sup>123</sup> Furthermore, recent analysis by Bloomberg New Energy Finance predicts the adoption of electric vehicles will accelerate.<sup>124</sup> This represents a fundamental shift, not just a low-carbon version of today's transport sector.

### Supportive technology policy

The extent to which developing countries can take advantage of being a first mover in the 4IR is likely to grow over coming years, as their capacity grows and the feasibility of new technologies increases. In the meantime, they have the potential to be fast followers, given that costs are reducing rapidly for many of these technologies and their applications. The timing of this uptake will be dependent on countries' initial infrastructure, skills, technological capability, appetite for risk and financing, and also their governance – including whether their technology policies are supportive.

Ensuring that policies support the adoption and deployment of innovative technologies is a major step towards maximising their potential. As Ockwell and Byrne (2016, p.143) note, it is important to have a “systemic understanding of how innovation and technological change can be nurtured through policy”,<sup>125</sup> including recognition that the incentives of incumbent stakeholders may impede the adoption of new technologies, and whether certain social innovations might bring about a different set of incentives that can help shift outcomes.

Supportive policy environments for technology can be aided by a number of organisations and initiatives. The Climate Technology Centre & Network, supported by the UNFCCC, provides technical and policy assistance and “facilitates the provision of information, training and support to build and/or strengthen the capacity of developing countries to identify technology options, make technology choices and operate, maintain and adapt technology”.<sup>126</sup> The United Nations University in Tokyo, Japan has a Low Carbon Technology Transfer research programme on the role of international cooperation and technology transfer.<sup>127</sup>

## Conclusions and recommendations

### Conclusions

Emerging and exponential 4IR technologies are already being developed and diffused, and they have the potential to disrupt current markets and bring significant opportunities for development. Policy-makers have a once-in-a-generation opportunity to harness these new technologies and achieve transformative changes within their societies. This report is intended to initiate discussion about the opportunities that these technologies can create for climate compatible development, and how we can harness these to achieve climate goals and the Sustainable Development Goals.

Among these climate goals are the NDCs. Countries are currently reviewing their NDCs ahead of implementation, and some are upgrading them to include greater ambitions ahead of the Facilitative Dialogue in 2018. As emerging and exponential 4IR technologies are developing on the same time frame as decarbonisation efforts under the Paris Agreement, these new technologies offer the potential to bring new opportunities for NDC implementation, such as the potential to broaden decarbonisation options in several sectors.

To realise this potential, countries' economies must be ready to embrace these new technologies. For many developing countries, the 4IR is likely to take place alongside the implementation and uptake of

currently available technologies. While some developing countries may have the existing or emerging infrastructure, skills and capabilities needed to harness the 4IR, others will need to ensure that they avoid lock-in to infrastructure that will soon become obsolete, which could limit their future technology options and lead to higher emissions over the medium term. Emerging 4IR technologies also bring potential risks, if governance and regulatory frameworks around their innovation and deployment are not well managed.

Policy-makers and development planners should consider these technologies and their implications when planning NDC implementation. Preparing for these technologies and including them in policies will enable them to take advantage of the technological benefits on offer, while managing the potential risks. And even though many 4IR technologies are still in development, the pace of innovation will be rapid if experiences with existing technologies (e.g. those in renewable energy) are repeated. Now is the time for decision-makers to be made aware of these opportunities, and to obtain buy-in from policy-makers and investors. To achieve this, NDC policy-makers need to understand, among other issues:

- what the latest technology trends are, and how they can help countries meet, and even exceed, the goals of the Paris Agreement and their own NDCs
- how emerging technologies interact and complement each other
- how the rapid – often exponential – deployment of emerging 4IR technologies enables them to obtain buy-in for, and eventually meet, their policy objectives – often more quickly than they currently expect.

In particular, policy-makers need to ensure that policies and investments foster the continued rapid deployment of existing technologies. They should invest in breakthrough innovations and technologies that expand the range of new applications and accelerate the pace of decarbonisation while developing the capacity of local firms to allow them to play a leading role.

Furthermore, developing countries should pursue technology options that are consistent with their needs and aligned with their cost and benefit expectations. They may need additional financial and technical support to put these into use, including from leading private sector technology firms. And these transitions need to be inclusive, so that everyone in a country benefits from the new technologies. We also see a role for the international development community: to embed sustainable and inclusive 4IR planning in developing countries. This should recognise that all countries can progress during the 4IR.

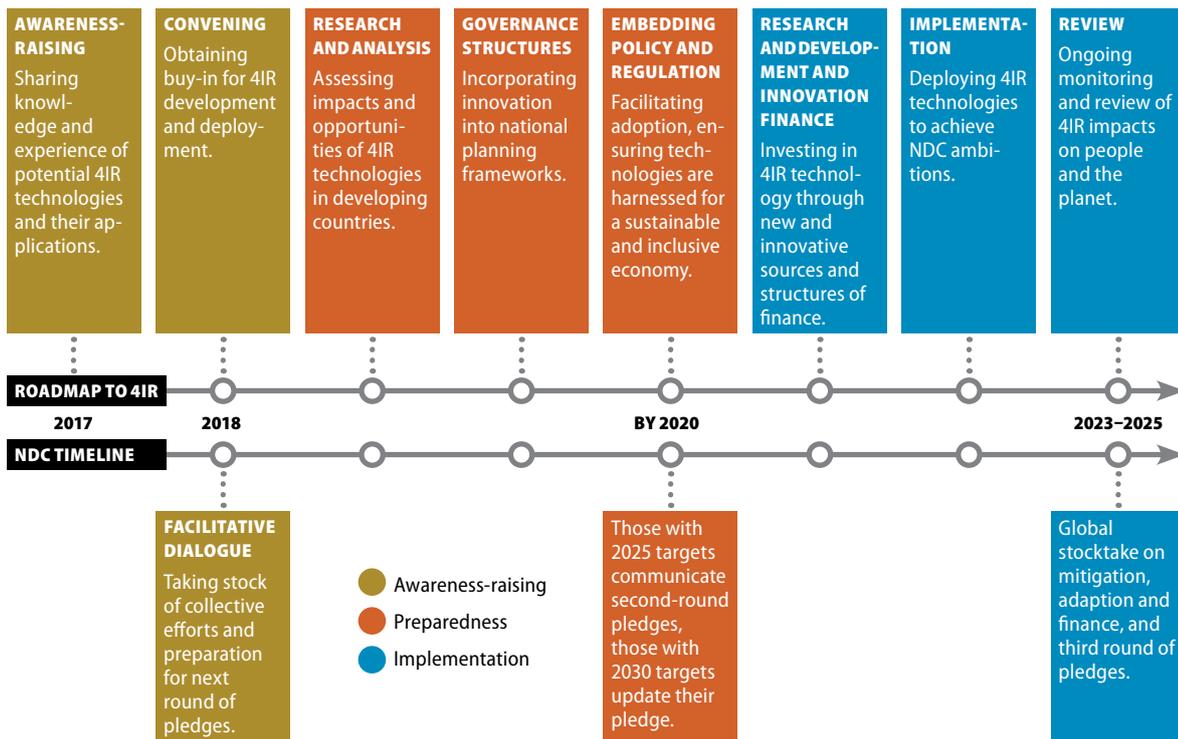
### Recommendations

Our recommendations detail the steps, across a range of areas, which will need to be taken as emerging 4IR technologies are designed, developed and deployed. Here, we outline the potential next steps for policy-makers in the different stages of technology development and deployment: awareness-raising, preparedness and implementation. Figure 3 summarises these.

Following the initial steps of awareness-raising, convening, and research and analysis, all countries will need to make appropriate arrangements that will enable them to fulfil the potential of the 4IR. These arrangements include the following priority areas.

### Governance, policy and regulation

- **4IR planning frameworks.** Given the potential for 4IR technologies to bring benefits, governments should incorporate flexibility within national planning frameworks, including those for NDC planning and implementation; this will allow for innovation in approaches to, and deployment of, technology. Governments can use existing networks, or develop new ones, to ensure collaboration with private sector actors, including start-ups working with emerging technologies that can accelerate progress towards climate change and sustainability goals.
- **Policy and regulation.** National and regional governments should recognise the benefits of facilitating the early adoption of 4IR technologies. To achieve this, countries may need to increase investments in training and capacity-building. This will help to ensure that their workforces have the

**Figure 3. Roadmap to 4IR planning and implementation**

Source: Authors' research and analysis

necessary technical skills, and that decision-makers can understand the potential for 4IR technologies to support a shift to a more sustainable, lower-carbon economy. Developing countries in particular have the opportunity to create a policy and regulatory environment that enables the scaling up of 4IR technologies that can support NDC implementation (e.g. emissions standards for automated electric vehicles, interconnection standards and net-metering policies for a distributed grid, efficiency standards for Internet of things devices and blockchain systems, and payment-for-performance mechanisms).

### Research and development, and innovation finance

- Research and development investment.** Governments should encourage greater investment in 4IR technologies, both their development and deployment, with a focus on their potential applications in developing countries. This will help them achieve their development goals and accelerate the implementation of their NDCs.
- Innovation finance.** Multilateral development banks, development finance institutions, the Green Climate Fund and bilateral donors should increase their focus on supporting the early-stage commercialisation of 4IR technologies. This should include developing public-private partnership financing structures, increased risk finance (e.g. grants, concessional grants and equity), innovation challenge funds, and innovation incubators for pioneering initiatives.
- Leapfrogging.** Leapfrogging to exponential and emerging technologies will require continual assessment and monitoring of the evolving potential and cost-effectiveness of technologies, individually and in combination, compared to less cost-effective or obsolete alternatives. Investment in business incubators, investment funds, pilot projects and the testing of potential applications will also help to build local capacity and markets which, in turn, will further accelerate the development and deployment of 4IR technologies. Policy and regulation will shape the economic and market conditions in which emerging 4IR technologies are developed, and into which they are deployed.

### Research and analysis: Economic and social impacts

- **Economic impacts.** Full economic impact analysis will be needed when considering the incremental impacts of individual 4IR technology options (or combinations), and compared to the costs and benefits of existing options. This will ensure that emissions-reduction pathways are implemented at the lowest cost over the technologies' life spans. A first step will be to collect and collate 4IR technology prices in local and specific contexts.
- **Societal and employment impacts.** Providing good job opportunities is an important aspect of the Sustainable Development Goals. It is important, therefore, that climate compatible development, when harnessing 4IR technologies, fully accounts for this and does not exacerbate unemployment. Potential job displacements will need to be addressed as 4IR options become an increasingly important part of NDC planning.

### Design and implementation

- **NDC alignment.** Each country's technology strategy should have meaningful, actionable steps for each sector, which bolster and reinforce key dialogues and support each round of pledges made during the NDC review process.
- **Inclusive economy.** To achieve a truly inclusive economy, the concept of inclusivity must be at the centre of decision-makers' thinking, not treated as an add-on. This means inclusivity being embedded into NDC implementation strategies and the design of action plans.
- **Partnerships.** Donors and governments will need to work with technology companies to ensure that developing countries receive a fair share of the benefits of the 4IR. This requires much deeper engagement with these stakeholders, especially business and finance leaders, to develop and support more sustainable and longer-term innovation pathways. Partnerships will also be required to create and develop sector-specific plans for development.
- **Digitally enabled development.** Donors will need to invest in their own skills and capabilities to design and implement 4IR-enabled development programmes. Programmes with a broader, countrywide mandate should also support capacity-building in developing countries so they are able to develop their own technological capabilities.
- **Data access and security.** Access to data may become increasingly valuable in a 4IR world. How data are managed, licensed and accessed needs to be reconsidered and re-evaluated, and changing security requirements should be considered and embedded in the design of any system generating or using data. Whether a policy of fully open data will negate the fundamental need for developing country data-sharing partnerships ought to be considered, and addressed where appropriate.
- **Entry points for the 4IR.** Innovation labs, such as those currently being led by the World Bank, could be an entry point to the 4IR for all countries. Other possible entry points include governments working with ICT companies or academic research departments, which could be supported by new initiatives and institutions.

Overall, we recommend that NDC and development policy-makers proactively engage in understanding the many potential benefits associated with emerging and exponential 4IR technologies. They will also need to find effective ways to manage the associated risks. But, if the benefits are grasped and risks managed, an inclusive, low-carbon, climate-resilient future for people and the planet could be within reach.

## Appendices

### A1. Details of the 10 exponential 4IR technologies

Technology	Description
Advanced materials	New materials, and developments to existing materials (e.g. lighter, stronger and more efficient to produce), which significantly improve functionality.
Cloud technology, including big data	Delivery of applications and services over the Internet can reduce storage and computer power needs. Cloud computing can be used to process large datasets to reveal previously unseen relationships and patterns (big data).
Autonomous vehicles, including drones	Air- or water-based devices and vehicles, for example unmanned aerial vehicles (drones) that fly or move without an on-board human pilot. Drones can operate autonomously (via on-board computers), on a predefined flight plan, or be controlled remotely. (Note: this category is distinct from autonomous land-based vehicles.)
Synthetic biology	Innovative adaptations to existing biological systems, relationships and pathways for new uses and applications. This merges the principles of biology and engineering to build artificial biological systems, such as synthetic DNA, biosensors and industrial enzymes.
Virtual and augmented reality	Virtual reality means computer-generated simulation of a three-dimensional image or a complete environment, within a defined and contained space (unlike augmented reality), that viewers can interact with in realistic ways. It is intended to be an immersive experience and typically requires equipment, most commonly a helmet or headset. Augmented reality means the addition of information or visuals to the physical world, via a graphics and/ or audio overlay, to improve the user experience for a task or a product. This 'augmentation' of the real world is achieved via devices that render and display said information.
Artificial intelligence	Software algorithms that can perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision-making and language translation. It is an umbrella concept made up of numerous sub-fields, such as machine learning, which focuses on the development of programs that can teach themselves to learn, understand, reason, plan and act (i.e. become more 'intelligent') when exposed to new data in the right quantities.
Robots	Electro-mechanical machines or virtual agents that automate, augment or assist human activities, autonomously or according to set instructions – often a computer program. (Note: Drones are also robots.)
Blockchain	Distributed electronic ledger that uses software algorithms to record and confirm transactions with reliability and anonymity. The record of events is shared between many parties and, once entered, information cannot be altered, as the downstream chain reinforces upstream transactions.
3D printing	Additive manufacturing techniques used to create three-dimensional objects based on digital models by layering or 'printing' successive layers of materials. 3D printing relies on innovative 'inks' including plastic, metal and, more recently, glass and wood.
Internet of things	A network of objects – devices, vehicles, etc. – embedded with sensors, software, network connectivity and computing capability, that can collect and exchange data over the Internet, which enables devices to be connected and remotely monitored or controlled. The term has come to represent any device that is now connected and accessible via a network connection. The industrial Internet of things is a subset, referring to its use in the manufacturing and industrial sectors.

Source: Eckert et al. (2016)<sup>128</sup>

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- 124 BNEF states: "We assume that current policies remain in place until they are set to expire, but we do not assume any fresh policies are introduced. We also do not assume any specific national climate targets are met." Bloomberg New Energy Finance (2017) *Electric vehicle outlook 2017*. New York: Bloomberg New Energy Finance, [https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF\\_EVO\\_2017\\_ExecutiveSummary.pdf](https://data.bloomberglp.com/bnef/sites/14/2017/07/BNEF_EVO_2017_ExecutiveSummary.pdf)
- 125 Ockwell, D. and Byrne, R. (2016) *Sustainable energy for all: Technology, innovation and pro-poor green transformations. Pathways to sustainability*. Abingdon: Taylor & Francis.
- 126 See: [www.ctc-n.org](http://www.ctc-n.org)
- 127 UNU-IAS (nd) 'Low carbon technology transfer'. Tokyo: United Nations University Institute for the Advanced Study of Sustainability, <http://bit.ly/2hXuaX7>
- 128 Eckert et al. (2016) Op. cit.





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