UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT

UNCTAD

NEW INNOVATION APPROACHES TO SUPPORT THE IMPLEMENTATION OF THE SUSTAINABLE DEVELOPMENT GOALS

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1. Introduction

Achieving the ambitious 2030 Agenda for Sustainable Development (United Nations, 2015) requires new innovation approaches that are socially inclusive and environmentally benign. This study presents several new and emerging innovation approaches, highlights how they may contribute to the achievement of the Sustainable Development Goals and discusses some of the policy implications in harnessing such approaches. It provides an overview of particular issues and considerations that need to be taken into account in coming years to maximize the contribution of new innovation approaches to sustainable development.

Chapter 2 introduces reasons explaining the need for new innovation approaches to help achieve the Sustainable Development Goals. Chapter 3 highlights the following five new approaches to innovation: mission-oriented; pro-poor and inclusive; grass roots; social; and digitally enabled open and collaborative. Chapter 4 proposes concrete policy considerations for Governments and other stakeholders, to strengthen capabilities for harnessing such new innovation approaches for sustainable development.

2. Why do we need new innovation approaches for the Sustainable Development Goals?

The 2030 Agenda for Sustainable Development puts forward a broad and ambitious agenda for global action on sustainable development. The scale and ambition of the Sustainable Development Goals require innovation in development and innovation for development. To achieve the Goals by 2030, new modalities for development are required, including bringing innovation into the foreground of development projects. Innovation, understood as new forms of social practice and organization, as well as new or improved technological products and processes, is not only an explicit focus of Goal 9 (build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation) but also a key enabler of most – if not all – of the Goals. For example, science, technology and innovation will play an essential role in achieving Goal 2 (end hunger, achieve food security and improved nutrition and promote sustainable agriculture)[1]. The ambitious nature of the 2030 Agenda – aimed at, among others, ending poverty and reducing inequality in all its forms everywhere, to promote inclusive and sustainable consumption and production systems, to provide full and productive employment and decent work for all – will require fundamental changes in the ways in which energy, food, water, housing, welfare, mobility and other goods and services are delivered, distributed and consumed.

Harnessing the positive potential for innovation to address the Sustainable Development Goals will also mean recognizing that some forms of contemporary innovation also contribute to environmental degradation, are disruptive of livelihoods and exacerbate inequalities. The key questions concern not how to encourage more innovation in more places, but which kinds of innovation need to be encouraged while at the same time discouraging harmful innovation.

Until the late 1980s, innovation was widely conceived as the commercialization of scientific discovery, mainly by large corporations that had the capabilities to exploit new knowledge (Schot and Steinmueller, 2016). This linear conceptualization of innovation (from science to research and development to commercialization) has since given way to a more sophisticated innovation systems model, developed within a normative framework focused on supporting national or regional competitiveness. Innovation is now recognized as mostly incremental – based on processes of adjustment to existing technologies, rather than on considerable novelty alone – and

[1] See UNCTAD (2017). The role of science, technology and innovation in ensuring food security by 2030.

is therefore recognized as involving practices and techniques that are new to a country or firm, as well as new to the world. A more recent understanding of innovation recognizes that capabilities are important not only in formal research and development but also in design, engineering, management and entrepreneurship, and that innovation in forms of organization and social practice, as well as in technologies, is relevant. Furthermore, innovation is seen as the outcome of a (difficult) process of learning and interaction between a diverse set of actors.

Public policy to support innovation has therefore broadened over the last 30 years (or at least attempts have been made in this direction), from a focus on support for centralized research and development programmes and the provision of incentives to large firms (for example, in the form of research and development subsidies and strong intellectual property rules) to one that also encourages human capital formation and capability development across a wide range of firms, and that facilitates interactions and linkages between firms and across firms, science and technology institutions, users and other actors. The underlying normative framework remains, however, one of supporting economic growth, with productivity increase at its core, and this is underpinned by the assumption that innovation-led growth is a key driver of social progress and the improvement of human welfare (Schot and Steinmueller, 2016).

Viewed from a global development perspective, the central problem that has usually been highlighted in relation to contemporary innovation processes is that many developing countries have struggled to develop the necessary firm-level and system-wide innovation capabilities, and to create the appropriate forms of demand that enable a process of catching up to more advanced countries operating at the technological frontier. The result is low levels of productivity growth in many developing countries, and a failure to diversify the structure of their economies, with adverse consequences for employment generation and sustained economic growth.

In the context of the Sustainable Development Goals, there are two additional problems. First, economic growth over the last two decades has occurred in many countries alongside significant increases in both absolute poverty and inequality, although inequality between countries has decreased over the last two decades, mainly due to rising middle class incomes in Asia (Chataway et al., 2013; ISSC et al., 2016; Milanovic, 2013). Some researchers argue that this phenomenon – an uncoupling of economic growth and social and economic development – is partly associated with the kinds of technological change that characterize contemporary innovation processes (Chataway et al., 2013). The dominant innovation trajectory is one of primary factors explaining why enhanced growth co-exists with – and even in some cases increases – both absolute and relative poverty. Its dependence on high-quality networked infrastructure and reliance on skilled labour, as well as its capital-intensive nature, scale intensity and product portfolio (producing products that meet the needs of the rich) have the effect of disadvantaging the poor, as both consumers and producers. It also excludes large segments of the population in many countries from productive employment (Chataway et al., 2013). In short, dominant innovation trajectories fail to include significant numbers of people from the benefits of social and technical change, and these are disproportionately poorer and more socially disadvantaged groups, including rural inhabitants and women.

Second, some of the more dominant innovation processes have been highly detrimental to critical environmental services, the adverse effects of which disproportionately affect poorer countries and communities. It is widely recognized that this problem is unlikely to be resolved solely by developing incrementally more efficient techniques. More fundamental changes to systems of production and consumption, in fields such as energy, transport and food and agriculture – in both their technological and social practice dimensions – are likely to be required to avoid catastrophic changes to the environment, biodiversity and climate.

These three core problems point not only to the longstanding need to continue to develop innovation capabilities in developing countries – across a wide range of firms and other actors – but also to re-orientate and redirect innovation trajectories in ways that enable more inclusive,

socially just and environmentally benign patterns of socioeconomic development.

The last decade witnessed a changing geography of innovation (Marcelle, 2016). Innovation has been taking place not only in developed but also in developing countries, in both formal and informal organizations, as well as farms (Fu et al., 2014; Woodhouse et al., 2017; Zanello et al., 2014). There is growing recognition of the richness of dynamic experimentation with different ways of problem solving in the global South. Some of the new innovation approaches outlined in this study, such as pro-poor and grass-roots innovation, originate in developing countries (Radjou et al., 2012; Smith et al., 2016). Such innovation approaches recognize the needs of poor, grass-roots and marginalized communities and involve them in innovation processes. Those at the bottom of the pyramid (the poorest in society) represent a huge untapped market for small-scale entrepreneurs, as well as large multinational enterprises (Prahalad, 2004). The challenge in inclusive innovation is that small organizations are inherently frugal and agile but lack resources to achieve economies of scale, while large organizations have the resources to achieve economies of scale but are often slow to act. Partnerships between small and large, local and global, firms are needed.

2.1 Challenges and constraints in achieving the Sustainable Development Goals

The achievement of the Goals by 2030 requires addressing a range of resource constraints. UNCTAD research shows that it requires a step change in both public and private investment in developing countries, if an estimated annual $2.5 trillion funding gap is to be filled. Public sector action is indispensable, but on its own will be insufficient to meet demands across all Goals-related sectors. Private sector contributions – through both good governance in business practices and investment in sustainable development – are therefore critical to the realization of the Goals (UNCTAD, 2014a). In particular, at national levels, similar financial constraints exist and are exacerbated by shortages of human capital and skills and by poor infrastructure, especially in developing countries. Low-income countries have just 1.3 per cent of the world's researchers – in comparison with 6.4 per cent in lower middle-income countries, 28.0 per cent in upper middle-income countries and 64.4 per cent in high-income countries – and an average density of researchers 30 times lower than in high-income countries (UNESCO, 2015, table 1.3).

Given these constraints at multiple levels, as well as the socially exclusive, and environmentally damaging nature of most contemporary innovation trajectories, as outlined earlier, what kinds of innovation approaches can help countries to achieve the Sustainable Development Goals?

In recent years, a great deal of scholarly and policy attention has been given to a number of both novel and older – yet hitherto relatively overlooked – approaches to guiding, organizing, thinking about and incentivizing innovation at international, national and local levels. Often falling under labels such as inclusive innovation, frugal innovation and social innovation, many of these new approaches involve different ways of doing and applying science, technology and innovation (STI), to meet social needs. Some of these new approaches might be considered marginal, relative to the huge resources devoted to mainstream innovation processes.

These approaches describe highly valuable innovation spaces, in which societal attempts are made to imagine and practice novel and different ways of trying to reconcile and advance the ambitions of delivering both inclusive and greener forms of social and economic development. In doing so, the actors and institutions involved in the new approaches often enjoy a degree of freedom to innovate that is simply not available to incumbents locked in by prior investments, business models and other commercial and institutional commitments to existing, unsustainable innovation trajectories.

The ambitious and progressive agenda of the Goals presents a huge opportunity to foster, support the emergence of and experiment with new forms of innovation for sustainable development. There is considerable scope to recombine elements of the new approaches with those that are more mainstream to generate "hybrid pathways to sustainability" (Ely et al., 2013). Many such processes may be further facilitated by

increasing digitization, providing important new opportunities for innovation.

2.2 Overview of the new innovation approaches

Some of the approaches presented in this study are new, while others are older but have been relatively overlooked. There is no consensus on a typology of new models or approaches to innovation in the literature. Recognizing the limitations in categorization of distinct innovation approaches and the complications arising from the ambiguous use of terms, emerging innovation approaches are not compartmentalized in this study into falsely distinct models, but rather discussed on the basis of the following broad themes:

- Mission-oriented innovation: Organizing networked research programmes at national or international levels, as well as the incentive structures that can direct innovation towards the achievement of specific technological, environmental or social goals.
- Pro-poor and inclusive innovation: Extending the beneficiaries of innovation, and building on ideas of innovation for the bottom of the pyramid (Prahalad, 2004). This focuses on pro-poor innovation (primarily in the private sector) which, through new concepts, low-cost labour and materials and huge scales of production, can serve markets previously ignored by traditional innovation. It also includes innovations by marginalized groups, introduced under conditions of resource constraints.
- Grass-roots innovation: Broadening the range of actors in the innovation process to include grass-roots innovation movements. The approach aims to practice innovation, in both technology and service provision, in socially inclusive ways.
- Social innovation: Shifting beyond technological to social innovation. This approach focuses on organizational innovations and new social practices designed to improve human well-being (for example, in business models, production practices and finance and public services delivery).
- Digitally enabled open and collaborative innovation: Fostering open, digital collaborations. Such innovation approaches draw on and recombine multiple sources and forms of knowledge, especially through digitally enabled open collaboration.

3. Introducing the new and emerging approaches

3.1. Directing innovative activities: Mission-oriented innovation

Mission-oriented innovation is concerned with directing innovation towards the achievement of specific technological or social goals, or to resolving social problems. It typically seeks solutions (or to address problems) that are considered undersupplied (or less attended to) by markets. Mission-oriented innovation is by no means novel. The Manhattan and Apollo projects, for instance, are examples of the wide range of post-Second World War publicly funded mission-oriented research programmes in the fields of defence, agriculture, energy and health, in particular (Foray et al., 2012). Governments throughout history have sponsored a wide range of initiatives to encourage innovations to address the most pressing needs, such as the Longitude Act by the British Parliament in the eighteenth century, an inducement to develop a practical method for determining a ship's longitude at sea (Murray et al., 2012). A recent and successful example of a grand challenge is that set in response to the outbreak in 2014 of Ebola virus disease in West Africa (see box 1).

Box 1. Fighting Ebola: A Grand Challenge for Development (relevant to Goals 3, 9 and 17)

As a response to the outbreak of Ebola virus disease in 2014 in West Africa, the United States of America Agency for International Development launched "Fighting Ebola: A Grand Challenge for Development", to connect with traditional and non-traditional partners worldwide to identify ideas to improve infection treatment and control. On the front lines of the epidemic, health-care workers faced many obstacles in providing the timely care to patients required to prevent the virus from spreading. In two months, innovators from around the world submitted over 1,500 ideas focused on helping such front-line health-care workers to provide better, more timely care and to contain the virus. Of the submissions, 14 innovations were identified for their potential to reinforce the response to the current outbreak and future outbreaks. The award nominees fell under the following six categories: increasing the protection and comfort of health-care workers and patients; improving health-care worker tools; decontaminants; rapidly deployable care settings; behavioural changes; and cutting-edge health-related information technology solutions to enhance the current response and provide a bridge towards longer term recovery.

To make an innovative idea happen can be a time consuming and difficult process with plenty of uncertainties. Yet some of the 14 award-winning ideas are already reaching users in the field. For example, a wearable patient sensor that monitors analytics was submitted for user testing in 2015 in Sierra Leone. A low-cost, battery-powered infusion monitor won approval from the United States Food and Drug Administration. User testing of personal protective equipment developed at John Hopkins University started in 2016 in Guinea and Liberia and will be commercially produced by DuPont. Barrier technology to prevent contamination is undergoing laboratory testing, while a decontamination chamber and a powdered bleach additive are undergoing user testing in Liberia. Finally, the producers of a dynamic, integrated health worker communications and coordination system called mHero have received additional funding to expand the scope of their work in Sierra Leone.

Source: United States Agency for International Development (2015).

The rationale for mission-oriented innovation fell out of favour in the 1980s and 1990s (although it has been consistently maintained in military research and development), reflecting concerns about the inability to pick winners and the view that Governments should only respond to market failure (Mazzucato, 2013). More recently, however, attention to, and a wide range of investments in, mission-oriented innovation had reflected a weakening of traditional market-oriented principles and a focus on what are known as grand societal challenges (such as climate change, ageing, inequality and chronic and infectious diseases). Some such challenges require the transformation of entire technological systems and the activities of foundations, beyond pushing for private sector-oriented ideas of innovation as a means of addressing social problems.

3.1.1 Potential contributions to the Sustainable Development Goals

Contemporary mission-oriented innovation programmes range from national to international, private foundation to public and/or private-sponsor initiatives, of varying but often substantial scales. Contemporary examples relevant to the Sustainable Development Goals include initiatives directed to delivering specific medical solutions – such as malaria eradication techniques and vaccine delivery systems that do not require refrigeration (Goal 3) and green energy technologies (Goal 7) (Bodnar and Turk, 2015; Varmus et al., 2003) – and more general programmes – such as those concerned with innovative responses to problems related to access to safe water (Goal 6), food security (Goal 2) and climate change (Goal 13) (European Commission, 2013). Prominent examples include the following:

- State-funded programmes, such as the Grand Challenges for Development of the United States Agency for International Development (including initiatives such as Scaling Off-Grid Energy, Securing Water for Food and All Children Reading), Grand Challenges Canada[2] and the seven-year Horizon 2020 research programme of the European Union. Such programmes support innovators, largely through calls for international research collaboration to solve challenges in sectors such as health, energy, water, food, education and governance and accountability.
- Large multilateral initiatives, such as Mission Innovation, a commitment in 2015 by 20 countries to accelerate public and private global clean energy innovation.
- Initiatives led by philanthropic organizations, such as the grand challenges programme of the Bill and Melinda Gates Foundation, launched in 2003, which encompass both development and health objectives.
- State investment bank mission-oriented finance programmes that create demand (rather than supporting the supply of new technologies), in countries such as Brazil, China and Germany. For example, in 2012 alone, State investment banks invested $108.9 billion in clean energy projects (Mazzucato and Penna, 2014).
- Public–private initiatives such as the Global Alliance for Vaccines and Immunization (GAVI), which seeks to influence market mechanisms for vaccine development and procurement, and is an alliance between the Bill and Melinda Gates Foundation, UNICEF, WHO, the World Bank, donor governments, international development and finance organizations and the pharmaceutical industry.

Additional national and international cooperation efforts include international cooperation initiatives, such as the Internet-of-Things Innovation Challenge in 2016 in Indonesia (http://smk.dicoding.com), and initiatives that promote innovation in specific sectors relevant to the achievement of the Sustainable Development Goals, such as the following:

- Initiatives in Switzerland aimed at exploiting the potential of waste as a resource and promoting the production of goods in a resource-efficient and socially and environmentally friendly way[3]

[2] Contribution from the Government of Canada; see http://www.grandchallenges.ca/.

[3] Contribution from the Government of Switzerland; see http://www.kti.admin.ch/kti/en/home.html.

- The Thailand National Science and Technology Development Agency Folk Innovation Award in Agriculture and the forthcoming Grand Challenges Thailand, an initiative to bring together research, development and the innovation community to tackle key issues for development and global health[4]
- Programmes and centres in the Islamic Republic of Iran to solve challenges in areas such as energy and water and urban issues, for example, urban innovation centres and energy saving through mobile applications in Tehran[5]
- Measures in Bulgaria aimed at the promotion of environmental protection, energy production and energy efficiency[6]

Unlike traditional research programmes, many of these new mission-oriented initiatives seek to move beyond research and development, to actively support prototyping, scaling up and the commercial or public diffusion of new technologies. The Horizon 2020 strategy of the European Union, for example, will "cover activities from research to market with a new focus on innovation-related activities, such as piloting, demonstration, test beds and support for public procurement and market uptake" (http://ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges).

Such new mission-oriented initiatives typically seek to involve, and provide incentives to, a more diverse range of innovators than researchers alone, across public, private and civil society sectors, and outside of the national borders in which funding programmes reside (for example, by including developing country-based researchers and innovators). A concern with attracting a more diverse range of innovators than procurement approaches typically can attract (and therefore, in principle, the identification of more novel technological solutions), as well as a concern with problems that do not promise market rewards (and for which patent availability is therefore of little attraction), has led to experimentation with innovation prizes and advance market commitments.

Innovation prizes and advance market commitments

Innovation prizes (large monetary awards to innovators who provide the first or best solution to a predefined technological challenge) are an inducement to private investment in areas where market opportunities are not evident. They have the advantage of not requiring monitoring of performance where contracts (that is, procurement commitments) prevail, and of attracting a wider group of participants. For example, the Longitude Prize in the United Kingdom of Great Britain and Northern Ireland, a £10 million fund launched in 2014, will reward an innovator that can develop a cost-effective, accurate and easy-to-use test for bacterial infections, which will allow health professionals to administer the right kinds of antibiotics at the right time, thus helping to diminish antibiotic resistance (http://longitudeprize.org/). This mission was selected by the public, based on six possible missions identified through consultations with experts and politicians and workshop-based public dialogues. The aim is for anyone, from an amateur scientist to the professional scientific community, to try and solve the problem.

Advance market commitments are a market-oriented mechanism to provide incentives for the private sector to invest, or to speed up investment, in areas that might normally be perceived as overly risky, such as the development and introduction of health technologies for developing countries. Unlike prizes, which reward the first supplier, advance market commitments can create a market of multiple manufacturers, with the advantage that this ensures both competition and sustainable production in the longer term. A well-known example is the Pneumococcal Advance Market Commitment, launched in 2009. For this initiative, a range of donors committed funds to guarantee the price of pneumococcal vaccines once they had been developed, thus providing vaccine manufacturers with the incentive to invest in vaccine research and development and expand manufacturing capacity in circumstances where they might not otherwise have done so. In return, companies signed a binding commitment

4 Contribution from the Government of Thailand.

5 Contribution from the Government of the Islamic Republic of Iran.

6 Contribution from the Government of Bulgaria.

to provide the vaccines at affordable prices to developing countries. The programme has successfully accelerated the development, and expanded the availability, of pneumococcal vaccines for developing countries (Cernuschi et al., 2011).

3.1.2 Policy implications

Much of the new wave of mission-oriented innovation, especially the area concerned with grand challenges, seeks outcomes that are broader than a single, specific area of technological capability and addresses problems that are more complex and much less well-defined, compared with those associated with the former post-Second World War mission-oriented research programmes. Many, if not most, mission-oriented innovation programmes have been organized in ways that are not restricted to national or regional borders and thus enable multilateral collaboration. Typically, funding calls encourage researchers and innovators from anywhere in the world to apply for support, and many programmes take the form of collaboration between countries and institutions. Therefore, in principle, large international mission-oriented innovation programmes may be more likely than traditional national funding programmes to support innovation capabilities in developing country settings.

However, despite the potential to support innovation capabilities, new mission-oriented innovation presents many challenges, including identifying and defining appropriate missions; creating incentive structures; ensuring long-term collaboration by many different actors and users (in both the development and deployment of a range of technologies); coping with the fact that there are often common resource problems; extending beyond national boundaries; and the need to replace incumbent technological practices with new ones (Foray et al., 2012). Among others, this means that mission-oriented innovation to tackle grand challenges will require long-term commitments from a range of both public and private actors (Mazzucato and Penna, 2015).

An overemphasis on technological solutions can potentially detract from other reasons for developmental challenges (such as poor health systems, poverty, lack of access to basic needs, poor infrastructure and political instability). There is concern about priority-setting and whether certain prizes or grand challenges are commensurate with the scale of developmental challenges (Li and Johnson, 2015; Litzow and Bauchner, 2006; McCoy et al., 2009). Furthermore, some researchers have argued that grand challenges may overlook diversity and distributional concerns and potentially reduce space to deliberate issues of accountability and directionality (Brooks et al., 2009).

The governance mechanisms of the incentive structures associated with mission-oriented innovation are distinct as well, often involving a pooling of resources from multilateral, national and philanthropic organizations, and the creation of novel public–private institutions (such as GAVI, in vaccine development and delivery). There are important questions about how the new governance arrangements define their missions, how the benefits arising from innovation are appropriated and distributed and how governance processes address competing perspectives on what the problem is and what constitutes its resolution (Kremer and Glennerster, 2004; Kuhlmann and Rip, 2014). There is a risk that the latter may be done in ways that differ from, or that are less diverse than, the ways in which national-level public institutions have previously identified priorities and directions for mission-oriented research programmes (which include more horizontal or systemic interventions). For example, some philanthropic organizations have been criticized by public health scholars for an overly science and technology-focused definition of the impediments and solutions to improving health in developing countries (Birn, 2005; Storeng, 2014). Policymakers may find it beneficial to involve multiple stakeholders and make the framing of mission-oriented innovation programmes more participatory.

3.2. Extending beneficiaries: Pro-poor and inclusive innovation

Approaches to innovation that are concerned with extending the number of beneficiaries, also referred to as pro-poor and inclusive innovation, aim to actively include and involve poor people

in mainstream processes of technology-related development, either as consumers in new product and service markets or, more ambitiously, as participants in innovation processes themselves. The former – innovation for marginalized groups – is most closely associated with ideas about the bottom of the pyramid (Prahalad, 2004), originally a top-down management approach aimed at creating new markets for multinational companies among the poorest parts of the population. Here the focus is on innovating with regard to low-cost products that can serve untapped markets with new commercialization and distribution strategies. The latter – innovation by marginalized groups and/or with mainstream actors such as Governments, firms and research and development institutions – is often associated with ideas related to frugal innovation, which focuses on informal forms of innovation in contexts of resource constraints, in either grass-roots settings or companies. The work of UNCTAD on STI policies to promote inclusive development has shown that to increase the effectiveness of such policies, it is important for inclusive innovation programmes to be designed using an integrated approach that includes not only the agents involved in the implementation of such programmes, but also their beneficiaries (UNCTAD, 2014b).

3.2.1 Potential contributions to the Sustainable Development Goals

Both innovation for and innovation by and with marginalized people have the potential to address many of the Sustainable Development Goals. The former, by taking advantage of existing resources and capabilities within firms to develop simple, down-to-earth solutions, can make services and products available that might otherwise be unaffordable. A well-known example of this type of innovation is the General Electric ultrasound scanner (see box 2). The development of new, cheaper devices based on existing technologies can create new markets and serve unmet needs among poorer populations, providing high-value products and services. Another example of an innovation aimed at promoting locally developed solutions to serve local needs, detailed in box 2, is currently being implemented in India through a collaborative project between the Government of Germany and Bosch.

Box 2. Examples of innovations for and by marginalized groups

General Electric low-cost ultrasound scanner (relevant to Goal 3)

General Electric's primary business in health care is high-end, expensive medical imaging technology. By the 1990s, General Electric technology in ultrasound imaging had a strong position in the developed world market, yet struggled in developing countries for a number of reasons, including high costs, lack of portability and complexity of use of the technology. The company was unable to serve emerging markets with this technology. Therefore, in 2002, it developed a less expensive version of the ultrasound scanner (sold at $30,000) that could be connected to a laptop computer and, in 2007, introduced an even lower priced version (sold at $15,000), of which sales grew dramatically, gaining a market of around $280 million. The portability, ease-of-use and low cost of the scanner triggered new uses, allowing it to be fitted into ambulances and emergency and operating rooms. The development was key for markets such as China, where the rural population did not have access to sophisticated medical services. However, it also allowed the company to develop new, premium versions of the scanner that were sold in the United States and other developed markets. Thus, the capabilities accumulated for pro-poor innovation subsequently led to low-cost product development for richer markets.

This example shows how a highly complex technology can be translated to different contexts using a frugal approach: A device originally designed for high-end markets becomes adapted to infrastructure-constrained situations in other markets and, as a result, helps to serve a market in other developing countries, but also eventually in the global North. Another way in which this approach is being replicated across the global

South is through the use and translation of business models to other similar contexts (see box 4).

Promoting locally developed technological solutions in India (relevant to Goal 3)

In India, the German Development Cooperation is working with Bosch on providing affordable technology-based solutions in key areas related to the Sustainable Development Goals, for example by supporting health suppliers in order to benefit low-income patients and expand access to better health services. One such solution is a locally-developed eye-care system that screens and detects eye diseases. The system, composed of both hardware and software, is more affordable for individual practices and health suppliers than those of competitors. In a country in which nearly one in every three citizens is visually impaired, the provision of such a product can impact a significant number of lives – an estimated 80 per cent of vision loss cases in India are preventable if detected early.

Supporting smallholders with a mobile-enabled platform (relevant to Goal 5)

The United Nations Entity for Gender Equality and the Empowerment of Women has developed Buy from Women, a mobile-enabled supply chain enterprise platform for cooperatives, connecting women to information, finance and markets. The platform connects men and women smallholders to the agricultural supply and value chain, and provides critical information on weather, market prices and incoming opportunities via text messages. Through the platform, farmers can determine the exact size of their land and forecast production.

Sources: Contributions from the Government of Germany and the United Nations Entity for Gender Equality and the Empowerment of Women; Immelt et al. (2009).

In order to create new markets in areas where there is a lack of infrastructure or a lack of experience in logistics and distribution, this approach can take advantage of new methods such as the use of online tools and social networks (Prahalad, 2004). In addition, this approach mainly focuses on the inclusion of the poor in consumption rather than in the innovation process. However, the provision of new products and technologies for marginalized groups can also be an important enabler, fostering familiarity with new technologies and allowing for the development of new capabilities (Hanlin and Kaplinsky, 2016).

There is perhaps greater potential to address the Sustainable Development Goals with those initiatives that seek to involve and include poorer people in innovation processes themselves. Here, the orientation is towards using existing resources and drawing on the knowledge of poor communities, in order to foster creativity in conditions of scarcity, thus allowing for the creation of potentially more resilient solutions to people's problems (see box 3).

Different kinds and levels of inclusion are associated with such ideas, ranging from the inclusion of problems and issues from marginalized communities into research and development agendas to enabling marginalized groups to participate in the process of innovation; facilitating the adoption of innovations from marginalized groups; and creating innovations that have some measurable impact on the lives of marginalized actors (Foster and Heeks, 2013).

3.2.2 Building capabilities

Instead of pursuing top-down strategies of technological development that generally disregard local idiosyncrasies and social asymmetries, pro-poor and inclusive innovation approaches (such as the Unilever Shakti initiative; see box 4) often try to recognize and use local capabilities and existing informal networks with NGOs and other institutions. However, even when they recognize the role the poorest may have in the innovation process, in practise, many of

Box 3. Mitti Cool refrigerator (relevant to Goals 1, 2, 7 and 9)

An example of frugal innovation is Mitti Cool, a low-cost refrigerator made of sustainable materials that works without electricity and uses built-in clay and water evaporation as a cooler. It can be easily built, at a cost of around US$30–US$50, and can keep food fresh for 2–3 days. Mitti Cool, launched in 2005, benefited from interactions with the Grass-roots Innovation Augmentation Network (GIAN), which supported product development, and has also been supported by the National Innovation Foundation of India. Its inventor was awarded a National Award at the Fifth National Competition for Grass-roots Innovations and Traditional Knowledge in 2009. Mitti Cool was granted an Indian patent and is currently on sale.

Source: National Innovation Foundation, India (2009).

the programmes based on pro-poor innovation are more focused on building capabilities in entrepreneurship than on knowledge or on creating bridges between local needs and conventional innovation (UNCTAD, 2011).

Furthermore, many of the innovations involved in this approach may be regarded as a simplification of already available products or processes. Their translation into frugal products does not necessarily involve users, cutting short any possible participation and missing an opportunity to develop local production capabilities. However, used appropriately (with a focus beyond the technology alone, to include training and network-building), this approach could help to support the development of local capabilities (such as software development and technical maintenance) among institutional actors and to foster experimentation with new and unexpected forms of application (Chan, 2014). Thus, combining inclusive innovation approaches with other interventions such as public procurement, extensive training and shared use of resources such as blueprints and software, and allowing users to adapt and modify innovations, could help more robust and sustainable innovation to be devised as part of social inclusion policies.

Box 4. Unilever Shakti: Inclusive innovation with non-governmental organization networks (relevant to Goals 3, 5 and 8)

The Unilever Shakti ("strength" in Sanskrit) initiative is an example of how pro-poor approaches try to set up networks. The initiative incorporated an alliance between Unilever and the Cooperative for Assistance and Relief Everywhere (CARE), a non-governmental organization with a history in capacity-building and women's empowerment in poor communities. Unilever aimed at developing new distribution channels to reach poorer consumers in small communities in India with low-cost products, such as shampoo and cream. CARE provided a platform for women's training in the rural sector, while Unilever funded courses in health, sanitation, infant care and entrepreneurship. Additionally, Unilever provided microfunding for business development. As a result, Unilever acquired a platform to sell its products in new markets in India. In 2012, the project reached more than 3 million households, creating employment opportunities for around 50,000 women that distribute its products.

Sources: London and Davidson (2011); *The Economist* (2012).

3.3. Broadening the innovation process to include grass-roots actors

Approaches that broaden the innovation process can involve social movements and networks of academics, activists and practitioners experimenting with alternative forms of knowledge creation and innovation (Fressoli et al., 2014). Such initiatives seek to practice innovation, in both technology and service provision, in ways that are socially inclusive towards local communities in terms of the knowledge, the processes and the outcomes involved. In contrast to mainstream innovation processes, which are led by firms operating in formal markets, grass-roots initiatives operate in civil society arenas, typically within a social economy of community and voluntary activities and social enterprises, rather than the formal business sector. This type of innovation is often driven by social and environmental needs rather than motives of competitiveness and profit in the market economy. It draws on resources such as grant funding, mutual exchange and voluntary input rather than commercial finance, and relies more on local, situated forms of knowledge, compared with scientific and technological knowledge.

Table 1 highlights some key stylized differences between grass-roots innovation and more mainstream innovation processes, in terms of actors, values, incentives, knowledge and sites of innovative activity. In practise, there is often more interdependence and interaction between the two approaches.

Table 1. Approaches to innovation of mainstream science, technology and innovation institutions and grass-roots innovation movements

Characteristics	Mainstream science, technology and innovation institutions	Grass-roots innovation movements
Political dimensions		
Predominant actors	Universities; public labs; commercial firms; ministries and other public institutions; international funding agencies	Civil society; non-governmental organizations; social movements; cooperatives
Priority values	Scientific advance for profit and innovation; not necessarily focused on social inclusion	Social justice; not necessarily focused on for-profit innovation
Mechanisms		
Principal incentives and/or drivers	Market demand; regulation and scientific competence	Social needs; cooperation and community empowerment
Sources of investment	State and/or corporate funding, venture capital	Development aid; community finance; donations; State funding
Forms of appropriability	Intellectual property framework strongly biased towards patent-based innovation	Common good
Knowledge dimensions		
Sites of innovation	Laboratories and research and development institutes; board rooms and ministries; market-based firms	Community projects and participatory processes; social movements
Predominant forms of knowledge	Scientific and technical knowledge	Local, situated knowledge; indigenous knowledge
Emblematic technological fields	Biotechnology; ICT; nanotechnology	Organic food; small-scale renewable energy; water and sanitation

Source: Fressoli et al. (2014).

Grass-roots movements are different from mainstream innovation processes in the ways in which activists and practitioners mobilize people around innovation and technological design. They may be characterized by three main features. First, they are based on collective action and solidarity and experimenting with different forms of bottom-up organization that combine local spaces, such as technology demonstration centres and makerspaces (see box 5), with wider regional or international networks. Second, they encourage participation in technological development as a means of increasing democracy. In practice this means not only participating in developing solutions to local problems but ultimately in gaining a voice in wider debates on technology and the directions of development. Finally, by attempting to encourage participation and solidarity, grass-roots innovation movements have, over time, devised many mechanisms to foster collective sharing of, and collective learning about, technology. From the use of appropriate technology handbooks in the 1970s to the contemporary prevalence of tutorials on websites such as Youtube, grass-roots innovation movements are foremost about supporting open ways of designing and producing technologies (Smith et al., 2016).

Box 5. The maker movement (relevant to Goal 9 and potentially Goal 12)

An example of a contemporary grass-roots innovation movement is the maker movement, which has become a global driver of informal experimentation with technologies such as software, microelectronics, robotics and digital fabrication. This movement links traditional knowledge about carpentry, metallurgy and mechanics with new skills and technologies such as software programming and basic electronics. It encompasses several global networks of practitioners such as hackerspaces, fab labs and makerspaces, and includes a wide variety of craft skills and professions, such as designers, architects, electronic artists and scientists. The main aim of maker culture is to experiment with artefacts, modify them for novel purposes and create unrestricted access to technology.

The Internet has enabled the spread of maker culture by fostering practices of collaboration and learning, using tools such as online tutorials and the sharing of open designs that connect amateurs, practitioners and experts worldwide. The movement draws heavily on open-source technologies such as open software (for example, Linux and Python) and open hardware[7] such as the Arduino microcontroller or RepRap three-dimensional printers.

There is an entire ecosystem of knowledge interchange, learning and online collaboration around the maker movement based on the Internet. Websites such as https://www.instructables.com/, https://www.thingiverse.com/ or https://sourceforge.net/ allow practitioners to upload and share their own designs, software and tutorials in order to develop open software, build items ranging from toys to mini-robots and create or modify items ranging from a three-dimensional printer to a house. Such repositories have grown sufficiently as to begin to attract interest from companies.

Learning how to create or use tools in the maker movement is part of a strong innovative ethos that embraces entrepreneurship and sometimes fosters the creation of alternative business models, such as those based on providing services to users of free software or tools for experimenting with open hardware. At the same time, the maker movement advocates free information, open-source technology, a new economy of sharing and the search for more sustainable technologies. One of the main characteristics of the maker movement is that anyone with a technological query or problem can approach a hackerspace, fab lab or makerspace and try to develop their own solutions or ask for help and create new developments in collaboration with others. As such practices foster direct experimentation with technology, some authors argue that the maker movement is creating a new form of citizenship.

One study estimated that, in 2012, there were about 1,000 makerspaces worldwide. Many of the projects created at fab labs and makerspaces seek to fulfil personal interest, while others seek to experiment with solutions for social inclusion, such as the creation of three-dimensional printed prosthetics. There are also more ambitious projects that aim to challenge traditional technological practices, such as those of farming by developing open-source and low-cost tools that can enable sustainable farming, for example through the Global Village Construction Set project of Open Source Ecology (see box 14).

Sources: Anderson (2012); Ratto and Boler (2014).

[7] Open hardware, or open-source hardware, refers to the design specifications of a physical object that are licenced in such a way that the object can be studied, modified, created and distributed by anyone. Open hardware is a set of design principles and legal practices, not a specific type of object. The term can therefore refer to any number of objects, such as automobiles, chairs, computers, robots and even houses (http://opensource.com/resources/what-open-hardware).

New grass-roots innovation networks have received considerable interest and have begun to be replicated around the world. Hackerspace, fab lab and makerspace are terms often used interchangeably to describe community-operated primarily non-profit workspaces where people with common interests in computers, technology, science or other skills can meet to collaborate as well as to socialize (see box 6). They are often located in social centres, education centres, public schools, libraries or universities, and are similar in that they offer public and shared access to high-end manufacturing equipment.

Given the long history of experimentation and design with regard to solutions for environmental and social problems, grass-roots innovation may contribute to the majority of the Sustainable Development Goals. Beyond specific technologies, areas where grass-roots innovation movements can make unique contributions are in alternative forms of education, innovation, consumption and local and global partnerships for achieving the Goals.

Box 6. Fab labs

Fab labs evolved from an initiative in 2001 at the Centre for Bits and Atoms of the Massachusetts Institute of Technology (MIT). Fab labs provide computers and computer-controlled tools that allow community members to develop software code and technology-enabled products. They are considered an MIT franchise and have a specific set of space requirements, required tools and supporting software. They are required to be open to the public for little or no cost, and they provide a platform for learning and innovation, as a place to play, create, learn and invent. As with the adoption of appropriate technology in the past, institutions such as universities, public research and development labs and commercial companies, such as Airbus, have adopted part of the fab lab approach, creating their own digital fabrication labs.

According to the Fab Foundation, there are approximately 1,050 fab labs around the world, in both developed and developing countries. Brazil, for example, has 32 registered fab labs, some of them focusing on knowledge sharing and community-building, and others hosted by universities and providing more equipment. There are seven fab labs in South Africa, several hosted by universities, focusing on youth and arts. There are six fab labs in Viet Nam, with profiles varying from health care, agriculture and education to traditional crafting.

Source: Fab Foundation (2017).

3.3.1 Potential contributions to the Sustainable Development Goals

Grass-roots innovation occurs in sectors as diverse as water and sanitation (see box 7), housing, food and agriculture, energy, mobility, manufacturing, health and education. Examples include community-based renewable energy initiatives, low-cost and low impact self-build housing developments, farmer-led irrigation systems, small-scale agricultural machinery development, urban food production schemes, community recycling, sanitation and water projects, local remanufacturing, low-cost refrigeration technologies, home-based nurse training schemes, farmers' markets and open-source energy monitors. They are supported by networks and social movements in both industrialized and developing countries. Traditional examples of this type of innovation include the appropriate technology movement, the People's Science Movement in India, the Social Technologies Network in Brazil and more recent initiatives, such as the global fab lab and makerspace movements (Smith et al., 2016).

Box 7. One Million Cisterns Project (relevant to Goals 2 and 6)

The One Million Cisterns Project (also known as P1MC) aims to provide a significant number of water cisterns in a large semi-arid region in north-eastern Brazil, which is characterized by low rainfall and scarce groundwater sources. The family-scale cisterns capture and store seasonal rainfall in sufficient quantities for both personal and productive needs (for example, agriculture) throughout the dry season.

The project was originally devised by the Semi-Arid Association, a network of more than 700 institutions, social movements, NGOs and farmers' groups, which later became an important actor within the Social Technologies Network (STN) in Brazil. The Ministry of Environment was also initially involved and, later, the Ministry of Social Development.

The main feature of the technology is that it is built by users (i.e. farmers and/or masons). The self-build aspect of the cisterns is intended to foster relationship-building in the community through the process of learning to construct, use and modify the technology. This empowers local communities, while providing autonomy from local governments and water suppliers.

The project was adopted by the Ministry of Social Development in 2003. Since then, almost 590,000 water cisterns have been built by local inhabitants with the support of STN and the Ministry of Social Development.

Sources: Fressoli and Dias (2014); Smith et al. (2016).

3.3.2 Policy implications

From the high levels of institutional support for the appropriate technology movement in the 1970s and 1980s, to contemporary interest in the maker movement, development agencies and mainstream science and technology institutions have historically shown interest in the alternative models of technological change and social development originating in grass-roots innovation movements (Ely et al., 2013; Fressoli et al., 2014). Policies to promote such movements include the following:

- The creation of programmes that provide funding to acquire tools and to experiment with new technologies and capabilities
- Initiatives aimed at building bridges between the informal, heterogeneous nature of grass-roots innovation and existing research and development capabilities
- Efforts to build infrastructure (such as repositories and innovation platforms) that can foster the distribution, replication and improvement of innovations and ideas from the grassroots with a wider audience
- Initiatives aimed at fostering international networks that can help to foster grass-roots movements at the local level and increase their visibility and legitimacy

It is nevertheless important to note that grass-roots innovation often thrives because of its independence from bureaucratic procedures and institutional traditions. It is therefore important for mainstream institutions to be careful not to impose their own objectives when providing support for grass-roots innovation. Grass-roots innovation efforts can thrive, for example, when due attention is given to process-based approaches instead of only to outcome-based models of support (that is, based on number of participants or technologies built). Furthermore, the desire to scale-up initiatives could potentially overlook the processes of empowerment and capacity-building that are at the core of grass-roots innovation movements.

3.3.3 Building capabilities

Grass-roots innovation movements can generate valuable knowledge and experience that complement existing research and development capabilities in developing countries. This can occur through the following means:

- Advocating and experimenting with alternative pathways of social and technical change: Over the last 50 years, grass-roots innovation initiatives (and their predecessors) have created technologies and social practices that were once considered radical, fringe activities, but are now mainstream or almost mainstream, such as organic

agriculture, wind energy, participatory design and agroecology (Ely et al., 2013).

- Challenging conventional innovators and innovation policymakers to learn how to engage with diversity: Grass-roots innovation develops and uses knowledge and technology in ways that are often different from formal institutions of science and technology. Such initiatives emphasize and foster the open character of knowledge production. They experiment, for example, with different ways in which citizens can help to define problems and issues requiring innovative solutions, and the underlying norms and rationales guiding the ways in which such solutions are defined.
- Recognizing other forms of knowledge and building bridges between informal knowledge and practices and conventional innovation processes: Grass-roots innovation movements have been key in opening up new spaces for innovation and recognizing the role of marginalized groups in developing their own solutions. For instance, in Latin America, the appropriate technology movement played an important role in retrieving and revaluing indigenous knowledge. Much of this involved the collection and study of botanical and agricultural knowledge from indigenous communities (see Smith et al., 2016).
- Empowering civil society actors to engage with technology tinkering and technology design and, ultimately, question the established research and development agenda: Grass-roots innovation movements are ultimately aimed at opening up discussion on the direction in which societies develop and change, and the roles of scientific research and technological change within those processes. As such, they raise questions about technological needs in societies, the appropriate directions of technological change and who is enabled to design, own and access technology, and on what terms.

3.4. From technological to social innovation

This section reviews approaches to innovation that focus on the creation and diffusion of novel social practices and institutions, as opposed to technical novelty and, in particular, to the idea of social innovation. This term, which has received substantial policy and academic attention over the last 15 years, is generally held to refer to innovations in social relationships, practices and structures that are primarily aimed at addressing social needs and at improving human well-being (Van der Have and Rubalcaba, 2016). The main driver for social innovation is the need to address unmet social needs. This distinguishes social innovation from non-technical innovations that take place within businesses and that are driven primarily by profit seeking, such as organizational innovation and innovation in services.

Understood in this way, most social innovations are initiated through entrepreneurial activities from the bottom up, by organizations and actors with roots in civil society and the third sector (such as cooperatives, associations and foundations). Social innovation thus overlaps with grass-roots innovation but, unlike the latter, it focuses only on innovations in social practices and organization. The institutionalization of global fair-trade production models (a prominent example of social innovation), for example, links social movements and producers and mainstreams firms and their associated norms in novel ways. Similarly, initiatives such as time banks (systems of reciprocal services exchanges) or novel means of fundraising and finance provision typically occupy a hybrid space between the State, the private sector and civil society (see box 8). One result of such hybridization is that it lends itself to experimentation with different organizational forms and practices (Pel et al., 2015).

Box 8. Time banks (relevant to Goals 8 and 10)

A time bank is a form of social innovation whereby members of a community can come together and help support each other through online platforms. For every hour of help provided, members can deposit time credits in a time bank, and they are able to withdraw equivalent support later when they are in need of help by a fellow member. As time banks are systems of exchange, they may be used in an almost endless variety of settings, and as a way of linking people in a community to share their time and skill sets. They also enable members to address loneliness and improve their health and well-being. There are over 290 time banks in the United Kingdom (http://www.timebanking.org) and over 200 in the United States (http://www.timebanks.org).

One example is the social enterprise Give and Take Care, founded in the United Kingdom in 2016, which works together with a charity for the elderly to match the skills of caregivers with the needs of the elderly (http://www.giveandtakecare.co.uk/). Every hour of volunteer work may be logged in the time bank, and exchanged for care later in life. This intertemporal care system, once it attracts a critical mass of members, has great potential to ease social and health-care pressures in ageing societies. The Government of the United Kingdom recently awarded £1 million to the organization to support its activities.

Source: *The Economist* (2016).

Recent examples of social innovation include energy cooperatives, forms of collaborative consumption such as car sharing clubs (see box 9), alternative currencies, new models of investment and ownership, novel forms of drug rehabilitation, education and training, and new forms of organization such as social enterprises and cooperatives (Boelman et al., 2014). Thailand, for example, has several successful social enterprises, such as Grass-roots Innovation Company, which promotes integrated organic farming by smallholders in rural Thailand, and ChangeVentures, which raises funds from social investors and social investment funds to support other social enterprises[8].

Box 9. Car clubs (relevant to Goals 11, 12 and 13)

Car clubs are an innovative form of collaborative consumption, in which consumers purchase access to a service, instead of owning and maintaining the asset that provides the service. The service is intended for people who occasionally require a car, thus providing a more sustainable alternative to car ownership. First experimented with in the 1970s by cooperatives and other groups of individuals who were ideologically opposed to mass car use, car clubs appeared as a more widespread phenomenon in the 1990s, mainly consisting of small non-commercial ventures, particularly in Germany and Switzerland, but also elsewhere in Europe and in North America.

Most car clubs take the form of an organization that rents cars to members on a short-term basis, typically in 30-minute increments. The fleet is dispersed in dedicated parking spaces throughout towns and cities. The system is collaborative in the sense that the same physical asset is used by different people at different times, none of whom is the owner. Unlike traditional car rental, however, the clubs enable members to use cars for less than one day at a time, on as many occasions as they wish, from a location near their home and without interacting directly with staff or offices. Increasingly, car clubs are owned and managed by large commercial companies (for example, traditional car hire firms), as well as by smaller social enterprises. In 2011, about 1.25 million people in 26 countries were members of car clubs.

Sources: Shaheen et al., 1999; Shaheen et al., 2000; Truffer, 2003.

New and emerging social innovations

In recent years, substantial technological changes have reshaped the economy and global financial system. Innovations in payment (for example, mobile payment systems such as bKash in Bangladesh, M Pesa in Kenya and Smart in the Philippines) and credit are not only transforming the mechanisms of transactions and finance, but also have the potential to reach and meet the needs of millions of people without access to formal financial services. Crowdfunding, peer-to-peer lending and social impact bonds (see box 10)

[8] Contribution from the Government of Thailand.

are new ways to access capital, creating alternative sources of finance and contributing to community and business initiatives that might not be able to obtain funds through traditional credit markets.

Box 10. Innovations to creatively provide access to financial capital (relevant to Goals 8, 9 and 10)

New approaches are also reshaping traditional ways to access capital, creating alternative sources of finance and contributing to community and business initiatives that might not be able to obtain funds through traditional credit markets. Some emerging fundraising models include the following:

- Online crowdfunding platforms (such as Crowdfunder, Indiegogo and Kickstarter), which propose two business models. Funders either donate to members with business ideas in return for products, perks and rewards, or businesses seeking capital sell ownership stakes online in the form of equity or debt. Crowdfunding is currently predominant in the developed world, but could become an important tool for fundraising in the developing world. For instance, in the Islamic Republic of Iran, websites such as https://hamsaa.ir/ and http://ichallenge.ir/ are platforms for crowdsourcing solutions for both public and private needs.
- Peer-to-peer lending, which is the practice of lending money to consumers and businesses through online services that match lenders with borrowers (such as Zopa and Funding Circle in the United Kingdom and Prosper and Lending Club in the United States). Platforms such as Kiva, for example, allow people to lend money online to low-income entrepreneurs or students in developing countries.
- Social impact bonds, which are an emerging financial mechanism for the public sector, to improve the delivery of public services. Socially motivated private investors pay upfront for a set of interventions to improve a social outcome (such as housing, health, education and welfare) and receive payments from public commissioners based on the results achieved by the projects. Social impact bonds are at an early stage of exploration, mainly in developed countries (such as Australia, the United Kingdom and the United States), yet their pay-for-success approach could be a model for projects in developing countries, such as South Africa, where some initiatives have been launched.

Sources: Contribution from the Government of the Islamic Republic of Iran; Crowdfunder (2017); Funding Circle (2017); Indiegogo (2017); Kickstarter (2017); Kiva (2017); Lending Club (2017); Prosper (2017); Zopa (2017).

Another example is blockchain, a distributed ledger technology that records information shared by a peer-to-peer network using state-of-the-art cryptography (see box 11). While some such services may have the potential to reduce the financial dimensions of the digital divide, they may also reinforce or create new ones.

Box 11. Blockchain (potentially relevant to Goals 8, 9 and 10)

Blockchain, a distributed ledger technology that records information shared by a peer-to-peer network using state-of-the-art cryptography, is a component of bitcoin and other digital currencies that do not rely on traditional banking structures. Each member retains a copy of the digital ledger (a database) and must validate updates collectively, without a governing central authority. Bitcoin is one possible application of the blockchain technology, which may potentially be adapted to remittance transfers, fund transfers and land registries.

Bitcoin and other blockchain services are still in early stages, and a number of technological issues (for example, security, achieving a critical mass of users, the need for exponentially increasing computing power as the network grows and the coding of traditional contracts into computer-based rules) can hinder their wide use. The lack of regulatory oversight and the pseudo-anonymity of transactions may provide alternative mechanisms for illegal activities. Furthermore, currency volatility and cyberhacking could invalidate the use of blockchain platforms as credible, predictable and reliable.

Source: OECD (2016).

Such services have emerged as new solutions to minimize transaction costs and finance ideas that might not have been possible through traditional sources. They have the potential to address development challenges, for example, by cutting the transaction costs of remittances (Goal 10). The long-term effects of such innovative ideas are not yet known, and the relative size of alternative finance compared with traditional finance in the long term must be considered. There are many questions related to how to create capabilities in developing countries to harness such new technologies. They can reduce the financial dimensions of the digital divide (for example, in mobile banking and remittances), yet may also reinforce or create new divides (that is, if transactions become cheaper for those with access to innovative financial platforms and more expensive for those without such access).

3.4.1 Potential contributions to the Sustainable Development Goals

Given the explicit focus on addressing unmet human needs through new social practices and institutions, social innovation is likely to address aspects of the Sustainable Development Goals that emphasize inclusion and greater equity, especially in areas such as education, health, work and poverty reduction. Examples include the following:

- Education initiatives that cater to children who are unsuccessful in mainstream institutions
- Models of finance that provide credit to people not included in mainstream banking systems
- Models of agricultural production and distribution that improve the incomes and working conditions of small-scale producers and farm labourers
- Initiatives that build capacity within communities to advocate for their needs
- Novel mechanisms for coping with conflict, displacement and corruption

As most social innovations seek to address problems and issues that both States and markets may not address, or may fail to adequately cope with, they often constitute challenges to existing business models and systems of production and consumption or to incumbent models of social and welfare provision. As many studies point out, they can therefore usefully be thought of as forms of experimentation with novel, potentially transformative, institutional and societal changes (Kemp et al., 2015). This is highly relevant to the Goals, as attaining many of the Goals arguably requires transformative, rather than incremental, social and technological change (see, for example, Schot and Steinmueller, 2016). As such, many social innovations have substantial value as sites of experimentation with new ideas and practices, beyond their direct and immediate impact on beneficiaries.

It is important, however, not to exaggerate the potential of civil society-based social innovation.

Many initiatives struggle to remain viable with limited resources (of staff, time and equipment, as well as funding), and are usually unable to affect the wider structural causes of unjust and unsustainable social development that their interventions typically seek to remedy (Pel et al., 2015).

3.4.2 Policy implications

Over the last decade, policies to support and foster social innovations have been implemented in a number of countries. In part this reflects general interest in citizen engagement in innovation, but the main drivers are the need for new forms of providing public services; budget constraints; a desire to support a more user-based, demand–pull approach to public services; recognition of a disconnect in high-income countries between economic growth and well-being; and, in Europe in particular, stagnant economic growth and poor employment generation since the 2008 financial crisis (Bonifacio, 2012; Hubert, 2010; OECD, 2011; Totterdill et al., 2015).

Policy attention is typically motivated by a desire to encourage social innovation, to identify and foster innovations that appear promising, especially in areas of traditional public welfare and policy (such as youth development, employment training and education) and to transfer, replicate and scale-up those that work. For example, in the United States, the Social Innovation Fund provides both grants and managerial and technical support to community initiatives that displace "stale, ineffective" public programmes, describing itself as concerned with "finding what works, and making it work for more people" (http://www.nationalservice.gov/programs/social-innovation-fund/our-model). The European Commission also aims to encourage market uptake of social innovations, through funding mechanisms via its Employment and Social Innovation Programme, networking support, an annual social innovation competition[9] and the financing of research on social innovation and the conditions under which it can best be supported.

Social innovation interventions face a number of challenges. First, given the ad hoc nature and community-based origins of many social innovations, the dynamism and nature of civic interest is central to enabling informal, solidarity-driven entrepreneurial activity (rather than funding availability and governance arrangements more generally). This means the main drivers of social innovation are the ecosystem of networks and the groups and individuals bound together by a shared vision of solidarity (Millard et al., 2016). Yet this cultural context is difficult to affect through public policy, or at least through policies that are focused on innovation. Other policy areas such as education and culture, and other areas of public provision, are more relevant given their primary focus on social infrastructure and the civic realm. Researchers suggest that funding and other support (such as network facilitation, advice and training) remain important, but among the most useful policy interventions to encourage social innovation are likely to be efforts to promote open policymaking. That is, flexible modes of long-term collaboration between public bodies, NGOs, users and private actors, in order that a range of voices, skills, competencies and resources may be encouraged to, and can readily, come together around particular problems (Millard et al., 2016; Totterdill et al., 2015). However, such organizational culture changes can be difficult to foster.

Second, the desire on the part of policymakers to replicate, scale up and diffuse promising social innovations must confront the diversity of the local sociopolitical and cultural contexts in which social innovations occur and the related motivations, and it is thus likely to be difficult to easily transfer innovations from one local context to another (Millard et al., 2016; Pel et al., 2015). There is also a danger, in seeking to scale up and diffuse exemplars of novel social practice, of losing sight of some of the underlying motivations that energize and prompt innovations in the first place, which, for example, may be about fostering quite different social development pathways and social relationships to those championed by, or at least associated with, those mainstream institutions that are attempting to foster social innovation (Smith et al., 2016). There is also a risk of engendering scepticism that social innovators are being co-opted to substitute for effective public provision. Policy initiatives in support of social innovation

[9] In 2016, the social innovation competition involved a prize of €150,000 shared by the three best ideas to support the reception and integration of refugees and migrants in Europe (http://ec.europa.eu/growth/industry/innovation/policy/social_es).

are as experimental as the initiatives they seek to foster.

Finally, in terms of opportunities for international collaboration, most of the policy initiatives to support social innovation have, to date, had a national or regional focus. Nevertheless it is notable how many social innovations that have been successful, in terms of operating at scale (such as car clubs), have been readily implemented in many different jurisdictions.

3.5. Digitally enabled open and collaborative innovation

Collaborative innovation enables knowledge and technology to be produced across a multiplicity of actors and institutions, drawing from a large pool of both formal and informal knowledge. There are two key requirements for enabling collaborative innovation, namely open access to knowledge and wide participation in the process of developing ideas, products and technologies. What is novel in collaborative innovation is the greater use of the Internet, digital technologies and social networks to foster learning, enable the co-creation of (codified) knowledge and provide widespread access to tools, data and resources.

This combination of open access to resources with new modes of online engagement allows digital open collaboration to solve certain types of problems at a much faster pace than is possible in more traditional, closed, institutional arrangements for organizing innovation (see box 12). Some researchers have suggested that the mere fact of being able to share, validate or discuss different ideas, assumptions or avenues of inquiry, allows online communities, such as open science or open software communities, to amplify collective intelligence (Benkler et al., 2015; Nielsen, 2012). Collective intelligence works by increasing efficiency through avoiding repetition and maximizing the use of resources with the open sharing of ideas, and by allowing for dynamic efficiencies by drawing ideas from a huge pool of collaborators from different institutions, locations and disciplines and other forms of expertise.

Box 12. Forms of collaborative production

Open innovation 1.0 refers to new forms of collaboration between firms along value chains in order to enhance experimentation and research and development capabilities. The fundamental idea of open innovation 1.0 refers to the need for firms to connect their internal innovation with external ideas coming from other institutional actors, including suppliers, clients and public labs. An example of open innovation 1.0 documented by Chesbrough (2003) is the Xerox Palo Alto Research and Development Research Centre (Xerox PARC), which developed many of the ideas and innovations of the information and communications technology revolution – including the Ethernet network protocol (3Com), publishing technology (that led to Adobe) and graphical user interface for personal computers – yet did not profit directly from such technology. Instead, Xerox licensed many of these innovations and allowed employees to create their own companies.

Open innovation 2.0 is based on the idea that innovation should involve not only large institutional players such as companies and research and development labs, but also end users and civic actors. Although this is an evolving term, the basis of open innovation 2.0 is the possibility of creating interdependence among different actors in order to foster innovation. Open innovation 2.0 thus benefits from developments in social networks, Internet resources and new tools such as the use of big data to foster more fluid forms of interaction. In practise, open innovation 2.0 requires building connective infrastructure such as open data, web-based platforms and fab labs and/or civic labs in order to create knowledge interchanges between different forms of expertise and to seek the cross-pollination of ideas with a wider range of actors.

Open innovation 1.0 and open innovation 2.0 differ from commons-based peer production, in that they retain their aim to capture value through private mechanisms.

Source: Chesbrough (2006).

Key elements for widespread participation in open collaboration are the modularity of objects (that allows them to be set as independent tasks), fine granularity of modules (that allows for small contributions from different participants) and availability of low-cost integration mechanisms and quality control, including rules for social collaboration and open licences, among others (Benkler and Nissenbaum, 2006). Heavily based on the organizational mode of operation of open software, the new mode of open collaboration fosters new ways of producing knowledge in science (open science) and technology (open hardware).

Open, collaborative innovation is often facilitated through digital online networks, but can benefit from spaces where face-to-face interactions, relationship and trust-building can take place. These may take the form of hackathons or civic innovation labs (see box 13). They may also take the form of more permanent structures. One example of this kind of co-working space, where entrepreneurs can gather, network and receive access to mentoring, infrastructure and other resources such as financing, is the iHub complex in Nairobi, funded by a range of donors, including foundations and private-sector entities (http://ihub.co.ke/). It is one of a number of technology hubs across Africa, and differs from others such as Co-Creation Hub Nigeria, which, since its establishment in 2011, has focused on social issues (Espinoza, 2014).

Box 13. Spaces for open innovation

Hackathons

Hackathons are co-design marathons that originated in hacker culture to speed up the creation of solutions to certain problems. They are typically held over 1–5 days and organized around specified challenges. People assisting hackathons usually come from a variety of backgrounds and disciplines (such as software, electronics and social sciences). There are different models for a hackathon, but attendees usually self-organize in groups around a certain problem and compete to solve it using different approaches. Hackathons create bonds and a sense of community among developers and allow people to experiment with different ideas and learn about new techniques, yet do not necessarily produce new products or polished solutions. Public institutions and companies have begun to use hackathons to kick start new solutions to complex problems. For example, in 2015, the United States Agency for International Development organized a hackathon to design improved protective suits for medical professionals fighting the outbreak of Ebola virus disease. The hackathon involved doctors, engineers, public health experts and fashion designers, to design a prototype suit later chosen for funding by the United States Agency for International Development. In addition, for example, the medical technology hackathons of the Consortium for Affordable Medical Technologies in Uganda are 48-hour events that bring together clinicians, engineers, entrepreneurs, industry experts and end users to co-create and crowdsource innovations for pressing clinical needs and barriers to care in Uganda.

Civic innovation labs

Civic innovation labs are spaces supported by local and national governments focused on generating innovations to improve governance, public service management and citizen participation. Issues covered by civic labs include, for example, public transparency, transport efficiency and urban planning. They are usually based on participatory design techniques, often open to the public and may be characterized by collaboration between citizens and public officials, sharing public knowledge and experimentation or prototyping new solutions to urban and regional problems. Examples of such labs include the Office of Social Innovation and Civic Participation founded in 2009 in the United States, with the aim of pursuing civic innovations in the public sector, and the Ibero-American General Secretariat, which, since 2014, has been organizing civic labs in different cities in Latin America (http://www.ciudadania20.org/#about).

Sources: Contribution from the Government of Uganda; Broussard (2015); Newshour (2015).

Collaborative innovation combines participatory design techniques, as developed in grass-roots innovation movements, with the documentation and protocol practices found in science in order to create highly interactive forms of knowledge creation that are enhanced by the use of Internet and social networks (see box 14). Collaborative innovation may be regarded as a paradigm shift in knowledge production that includes open government, open science, open software, open hardware and new networks of collaboration and experimentation, such as the makerspaces, fab labs and hackerspaces. Although such approaches and fields share many characteristics and tools, they are not necessarily connected, and their communities of practice are often independent of one another.

Box 14. Global Village Construction Set (relevant to Goals 2, 7 and 9)

For example, the Global Village Construction Set of Open Source Ecology is an initiative to create 50 tools with open-source blueprints and instructions that a farm needs to be sustainable and autonomous. The philosophy of the project is that access to tools and machines is not a question of lack of resources, but of unfair distribution. By making available blueprints and instructions, the initiative seeks to make tools accessible to everyone, especially those in small communities, in order to help create a sustainable society.

The project has been experimenting with the village set for the last five years and has about 20 prototypes. It offers blueprints and instructions (including tutorials on Youtube) on how to make the tools, and offers in-house workshops. Sharing the designs online allows for a large network of people to collaborate in the design of machines and to improve and modify them to make them suitable for new uses. A survey in 2014 determined that 110 replications of the designs from the Global Village Construction Set were in use in Chile, China, Guatemala, India, Italy, Nicaragua, Turkey and the United States (http://opensourceecology.org/wiki/Replication).

The initiative is an inspiration for other makers and entrepreneurs, and can also provide lessons for existing research and development institutions. There are huge opportunities in opening up access to the technical blueprints of agriculture machinery, renewable energy and water and sanitation technologies already developed by research and development institutions. Making such designs available could help local actors gain new knowledge and develop their own tools and also help to improve available technologies.

Source: Open Source Ecology (2017).

3.5.1. Potential contributions to the Sustainable Development Goals

Many forms of open and collaborative production have already been heralded as practices that can help to address Sustainable Development Goals-related challenges. From the use of hackathons to finding solutions to Ebola virus disease and the use of citizen-driven data to monitor environmental and social phenomena (Fressoli et al., 2016) to open science and data-sharing schemes to solve neglected diseases (Masum and Harris, 2011), multiple initiatives are being pursued and tested (see box 15). Given the intractability of many of the problems that need to be resolved in order to address the Goals, a number of researchers have argued that the use of open and collaborative practices is helpful as it can diminish barriers to innovation, accelerate the pace of innovation and help foster a more democratic approach to resolving complex and contested issues (Masum and Harris, 2011; Nielsen, 2012).

Free software projects provide an example of open collaborative innovation. For example, proprietary operating systems such as Windows have faced significant competition from open-source alternatives such as Linux, which are developed through open and voluntary collaboration from software developers worldwide[10]. Open-source software is currently used by Governments, multinationals and citizens around the world, allowing tools to be adapted by users and lowering the economic and technological barriers to the use of computers in almost every aspect of the digital world.

[10] Microsoft has recently enabled open-source development by adding the Linux command line to Windows 10.

Although the practice of open and collaborative innovation has been successful in software, there are considerable challenges in trying to translate this approach to other areas such as open hardware and open science. Maintaining open designs and code and avoiding restrictive forms of appropriation are key, as are the challenges of encouraging the development of wider capabilities, in order that everyone interested can become a maker of their own tools, and of creating viable business models through which open and collaborative innovation can flourish. Without a significant empowerment of actors excluded from conventional innovation and development processes, the notion of open and collaborative innovation might easily remain a practice that is exclusive to elites and those who already have access to advanced technology. At the same time, the practice of open software is not easily translated into other areas such as open hardware due to material and capital requirements and increasing tacit knowledge requirements, among others. In other forms of open and collaborative production such as open science, open access to papers and data helps to democratize access to knowledge. However, there are still questions of accessibility – who has the knowledge and skill to use available scientific data – and participation – how citizens can help to produce scientific data and be empowered at the same time (Arza and Fressoli, 2016).

Box 15. Other forms of collaborative production (relevant to Goals 13 and 15 and potentially all)

Open science

Open science allows scientists to collaborate at different stages of a research process with scientists from other disciplines and in other parts of the world. In some cases, open science also calls for collaboration by the public in citizen-science projects, such as e-Bird (see box 16) and Galaxy Zoo, among others. Open science practices are inspired and generally based on similar principles as those of the open-source software movement. Open science practices seek to share the data, tools, problems, outcomes and efforts of producing relevant knowledge. Web-based and electronic tools have created huge opportunities to scale up and speed up openness and collaboration (see box 13). Supporters of open science state that such practices increase the efficiency of scientific production by fostering collective intelligence for the resolution of complex social problems, and that they empower local populations whose interests can be better reflected in research agendas, along with allowing better access to the latest scientific findings. However, open science may not be applicable in every context, and quality control may be problematic in some set-ups.

Citizen-driven data

Big data is sometimes regarded as the new oil of the twenty-first century and Governments, companies and civic organizations are increasingly interested in the potential role of data in development. For instance, the United Nations Secretary-General's Independent Expert Advisory Group on a Data Revolution for Sustainable Development argues that grass roots-based data production initiatives could have a relevant role in monitoring the achievement of the Sustainable Development Goals. Citizen-driven data is a practice that uses available data or produces new data in order to make visible hidden problems and processes and to create reliable information in relation to issues such as climate change, environmental pollution and inclusive development. Citizen-driven data generally relies on cheap, flexible tools, such as participatory workshops, web-based forms, mobile telephone applications, low-cost sensors and social networks, to collectively gather and distribute data with the help of engaged citizens. As data activism generally crowdsources information through voluntary contributions from the public and uses open-source tools, the practice can potentially be replicated and adapted by small organizations for a low cost. Examples of data activism include the Ushahidi[11] application in Kenya, the Territorio Indígena project by Amnesty International in Argentina[12] and the Technology-enabled Girl Ambassadors project in Nigeria[13].

Sources: European Commission (2016a); Fressoli et al. (2016); Woelfle et al. (2011).

[11] Ushahidi ("testimony" in Kiswahili) is an open-source project that allows users to crowdsource crisis information to be sent via mobile telephones. It was developed to map reports of violence in Kenya after the post-election violence in 2008 (http://www.ushahidi.com/).

[12] Territorio Indígena is an Internet platform that refers geographically to specific conflicts affecting indigenous communities. Over 180 conflicts have been included. The website invites visitors to supply information on conflicts not reported on the platform, using a specific form, and project organizers then validate the data collected (http://www.territorioindigena.com.ar/).

[13] The Technology-enabled Girl Ambassadors project trains girls and offers the opportunity to collect data on their everyday experiences. The project is operational in northern Nigeria and plans to launch in Ethiopia, India, Indonesia and Rwanda, with potential contributions to Goal 5 through the analysis of gender-specific data and provision of digital skills that can enhance girls' employment and other opportunities (http://www.girleffect.org/what-we-do/tega/).

Opportunities for international collaboration

The methods of open, collaborative innovation are spreading to other areas such as open science and open hardware, with implications for North–South, South–South and multilateral collaboration. The combination of open science and open hardware allows scientists in developing countries to obtain access to tools and instruments that are either expensive or difficult to import into their own countries. This open labware phenomenon is not circumscribed to marginal actors. The European Organization for Nuclear Research has been working on open hardware since 2013, recently launched a repository for open hardware and is promoting its own licence to share designs and knowledge while assuring the proper documentation of modifications (Gibney, 2016).

Similarly, the Open Labware initiative organized by Teaching and Research in Natural Sciences for Development in Africa, the Open Neuroscience initiative and the Baaden Lab, are promoting the collaboration and construction of low-cost, open scientific equipment for developing countries for educational and research purposes. The initiative includes designs and tutorials for the three-dimensional printing of tools such as optical fluorescence microscopes with optogenetics and temperature control, a motorized micromanipulator to handle very small biological samples (about 10 microns) and three-dimensional printed micropipettes (http://open-labware.net/). The consortium's article explaining the methods and uses of open hardware in lab equipment has been downloaded more than 50,000 times (Baden et al., 2015).

3.5.2 Building capabilities

Collaborative innovation allows diverse participants to contribute, in their own time, from different locations and on the basis of heterogeneous forms of expertise and qualifications. For instance, open science projects such as e-Bird (see box 16), have more than 300,000 contributors from very different backgrounds who share their time and expertise for scientific and recreational purposes. However, for such projects to thrive, there are certain minimal conditions that need to be in place, as follows:

- Basic literacy
- Internet connectivity and access to digital networks (without political, monetary or bureaucratic restrictions)
- Open access to existing scientific and technological information
- Flexible intellectual property rules that do not discourage users from contributing to projects, and that allow fair use of their contributions

Other contributing elements include physical spaces (such as makerspaces) that enable the use of online tools with hands-on learning and open repositories of scientific and technological knowledge. With regard to open science, there are also specific requirements for citizen participation such as the use of plain language, easy to use instruments, simple protocols for data collection and visualization tools to understand complex data.

Box 16. E-Bird: From citizen science to open science collaboration (Goals 13 and 15)

With more than 300,000 online collaborators globally, e-Bird is one of the most successful cases of open online collaboration based on citizen-science ideas. The platform was developed in 2002 in the United States by the Ornithology Laboratory at Cornell University and the National Audubon Society. It is a free access tool to manage and share online data of bird sightings by amateur and professional birdwatchers, built on the concept that each time a birdwatcher sights a particular bird, there is a chance to gather useful information. The platform makes use of free software tools and online collaboration not only to efficiently gather and archive data but also to distribute information about birds to a wider audience. The large amount of data collected by e-Bird on the spatial distribution of species and on population trends, for example, can help to identify important areas for bird conservation and contribute to the design of better plans for managing threatened species. Given the amount of data compiled by e-Bird, scientists have started to use machine-learning techniques and machine visualization to model migration patterns in the United States.

Source: eBird (2017).

There is substantial high-level interest among scientific institutions, funding organizations and policymakers in open and collaborative practices in both open science and open innovation (Boulton et al., 2012; Commission High-level Expert Group on the European Open Science Cloud, 2016; European Commission, 2016a; OECD, 2015; RIN NESTA, 2010; Rossel, 2016). Policies to support open access and national public repositories for science are also being implemented in countries such as Argentina, Mexico, Peru and South Africa (http://www.accesoabierto.net/politicas/default.php).

Public policy and institutional recognition in areas such as open science have focused on areas where there are existing capabilities or where it is easier to create them (such as requiring the use of open digital repositories). However, other aspects of open and collaborative practice, such as open hardware or citizen participation in data collection and analysis, have received comparatively less attention. These are precisely the areas of collaboration where the production of knowledge faces higher barriers, since they combine scientific expertise with other forms of informal expertise (such as community management and public communications) and/or because they require the use of novel participation techniques (Mansell, 2013). To realize the potential of open and collaborative practices will require combining technical hard resources such as data repositories with more soft capabilities such as organizational skills and new communications tools (such as data visualization techniques and webinars).

3.5.3 Policy implications

Collaborative innovation projects such as those in the field of open software and open hardware benefit from self-learning mechanisms such as online courses or online repositories and wiki websites that allow other users to follow protocol and learn in the process[14]. Such practices, coupled with increasing participation in open knowledge production, can help foster the development of new capabilities in science, engineering, design, electronics and software. However, as previously noted, open and collaborative practices could be very disruptive for incumbent actors who are afraid to share their knowledge and resources (see, for example, Sheliga and Friesike, 2016)[15]. In addition, tacit knowledge and some engineering skills are not easily translated into digital collaboration and could require years of apprenticeship. In order to face such challenges, there is a need to develop new incentives, models, infrastructure and skills that could help realize the potential of open collaboration, especially in developing countries. Some of the issues that should be considered in the design of open digital collaboration policies are the following:

- **Developing new online infrastructure:** Open collaboration platforms such as digital repositories for sharing data and technological designs, tutorials and massive online open courses could help to democratize access to available knowledge and foster the creation of new communities of practice.
- **Building tools for open and collaborative practices:** Although there is considerable interest in developing open access repositories for data produced by governmental institutions and scientists, there is much less interest in other services, such as public repositories for open hardware, platforms for citizen science and new communications tools. New infrastructure for open collaboration should strive to include as many participants from different backgrounds as possible, and to include them as active collaborators.
- **Building hybrid spaces of innovation:** One of the most challenging aspects of open and collaborative production is how to manage the diversity of participants and expertise available, and how to provide spaces that allow experimentation with new technologies and ideas. Many conventional institutions are sometimes reluctant to host open innovation spaces, such as makerspaces or fab labs, often related to the lack of capabilities and resources to manage such initiatives. Physical spaces are key to enabling meeting with other experts, learning by doing and creating new projects.
- **Documentation and inter-operability:** Another important aspect of collaboration is the need to develop protocols for good documentation of the development and

[14] For instance, massive online open courses create a new platform for distributed learning (http://unctad.org/meetings/en/SessionalDocuments/ecn162016d3_en.pdf).

[15] On the other hand, open source can be part of a competitive strategy for private firms. Some firms may create an open-source platform to commoditize software tools that would alternatively be provided through market competition. Furthermore, contributions to an open-source platform could help firms benefit from inputs outside firms as well as identify and recruit talent to firms.

inter-operability of data. This is more easily said than done, since information can come from many different institutions and disciplines. Finding ways to make open data available and easily legible by different actors is an important challenge for public policies.

- **Developing new incentives:** There is a need to develop new incentives for open collaboration and sharing data among research and development institutions and governmental offices. Such incentives need to find a way to balance established policies for the commercialization of knowledge and also to overcome cultural barriers to openness.

4. Key policy considerations

This study illustrates how new and emerging approaches to innovation can contribute, and already may be contributing, to the realization of the Sustainable Development Goals. It provides an overview of different approaches, characterizing them on the basis of broad themes, rather than compartmentalizing them into models.

The characteristics of the new models of innovation can enable them to better address the needs, interests and perspectives of poorer, marginalized communities, and better serve non-market and environmental goals than traditional, linear models of innovation or conventional innovation systems approaches. This is particularly important given the resource constraints faced by many developing countries, the current levels of innovation capabilities and the transformative changes necessary to realize the Sustainable Development Goals.

While each of the new and emerging approaches to innovation discussed above is potentially able to contribute to any of the Sustainable Development Goals, their utility is illustrated through case study examples in this study. Table 2 gives a summary of the different approaches and examples.

Table 2: New and emerging approaches to innovation, with illustrative examples and relevant Sustainable Development Goals

Section of study	Other labels	Inclusion potential	Capabilities required	Examples in this study (see boxes)	Relevant Sustainable Development Goals
3.1. Mission-oriented innovation	Grand challenges; global challenges	Variable, depending on mission	Finance; agenda-setting and good governance; coordination; sophisticated research infrastructure	Fighting Ebola: A Grand Challenge for Development	3, 9 and 17
3.2. Pro-poor and inclusive innovation	Bottom of the pyramid; frugal; jugaad	Inclusion of consumption and impact	User needs; scaling up; marketing; entrepreneurship	General Electric low-cost ultrasound scanner	3
				Mitti Cool refrigerator	1, 2, 7 and 9
				Unilever Shakti	3, 5 and 8
3.3. Grass-roots innovation	Inclusive; grass roots; informal	Inclusion of process and structure	User needs; empowerment; mobilization; Internet connectivity (in some cases)	Maker movement	9, potentially 12
				One Million Cisterns Project	2 and 6
3.4. Social innovation	Organizational; supply chain	Inclusion of impact, process and structure	Entrepreneurship; non-monetary incentives	Time banks	8 and 10
				Crowdfunding, peer-to-peer lending, social impact bonds	8, 9 and 10
3.5. Digitally enabled open and collaborative innovation	Innovation ecosystems	Inclusion of process	Basic literacy; Internet connectivity and open access; flexible intellectual property rules; infrastructure	Open Source Ecology	2, 7 and 9
				Citizen-driven data	13 and 15, potentially all

Science, technology and innovation policies related to the Goals must consider the direction, distribution and diversity of innovation pathways. They should also take into account the linkages and relationships between the different actors, as well as the skills and other framework conditions required for innovation. The 2030 Agenda for Sustainable Development provides an opportunity for policymakers to support the emergence of, and experiment with, new forms of innovation for sustainable development. There is considerable scope for recombining elements of new approaches with more traditional ones. This underlines the importance of policy coherence across government actors in the design of policy mixes. A coordinated approach is needed, widening the policy focus of innovation systems both in terms of the actors involved and the means of interaction and collaboration.

This chapter discusses general policy implications and recommendations and addresses considerations for strengthening capabilities in these new and emerging innovation approaches, with a specific focus on the role of digitization as an enabler of open collaboration. Furthermore, it considers the governance challenges associated with these new approaches, including considerations for priority-setting with multiple stakeholders. Finally, additional questions for policy and governance at national and international levels are considered.

4.1 Policies to facilitate new, emerging and hybrid innovation approaches

Each of the new approaches described above can make important contributions to the Sustainable Development Goals, as illustrated in the boxes. However, many of the most marked impacts will come from hybrids between them and more conventional approaches (Ely et al., 2013; Smith and Arora, 2015). Hybridization can occur, for example, when initiatives created at the grass-roots level, or through pro-poor innovation processes, for example, subsequently receive support (for example, in the form of investment, joint research and development and marketing) from more conventional science and technology institutions. The emergence of a large, successful commercial global wind energy industry, for example, has roots in the development of small-scale wind turbines and energy cooperatives in Denmark in the 1970s. At the same time, grass-roots initiatives may adapt technologies that have emerged from conventional innovation processes, such as the digital design and fabrication equipment that makerspaces draw on to promote commons-based forms of production. This attention to hybrid innovation approaches involves widening the policy focus of innovation systems (Ely and Bell, 2009), both in terms of the actors involved and their means of interaction and collaboration – a more general policy implication of this study. A notable example of the formulation of such hybrid policies is the Austrian Open Innovation Strategy, mobilizing actors in Governments, science, business and civil society to collaborate and innovate by spanning the boundaries of disciplines, sectors, regions and countries[16].

Warnke et al. (2016) consider this broadening of the innovation system to include new actors and intermediaries, pointing to "the need for a more radical revision of the innovation system analytical construct". The concrete implications of this new approach for policy are poorly understood and deserve future research (see section 4.5). However, general policy recommendations are noted in the following areas:

- Infrastructure and network facilitation
- Financing and incentives
- Regulation

Facilitating infrastructure and networks for innovation

Collaborative innovation involving commons-based peer production requires both digital infrastructure and material infrastructure to permit face-to-face encounters (coordinated or fortuitous) between innovation actors, such as through hackathons or other spaces for open collaboration (Smith and Stirling, 2016). Such forms of infrastructure can act in a similar way to traditional incubators (which provide services and resources to start-up firms, for example, in specific sectors) but reach out to broader groups. Institutional support to build bridges between formal and grass-roots innovation, other forms of infrastructure such as repositories and innovation platforms, and mechanisms for international network facilitation (see subsection 3.3.2), can further strengthen such hybrid activities.

Financing innovation and incentives for desirable innovation

Financial resources for the implementation of the Sustainable Development Goals remain inadequate. Therefore, there is a need to mobilize and scale up

[16] Contribution from the Government of Austria.

development finance allocated to investment that considers social and environmental objectives in support of the Goals. There has been significant attention paid to the linkages and relationships between Governments, universities and industry in science, technology and innovation-related policymaking. However, the importance of also fostering linkages with investors in relation to financing innovation has not been adequately recognized, especially in developing countries. To change the current allocation of investment, including foreign direct investment, it is necessary to change the mindset of investors, to help overcome financing constraints for innovation and the Goals. Partnerships between Governments, the private sector and academia should also include the financial sector. Efforts in this area should increase access to financial resources and improve their allocation.

Financing research and innovation based on specific missions can act as an important incentive for hybrid innovation and incentivize collaboration between different stakeholders (especially with the considerable amount of financial resources required, as outlined in section 2.1). Some researchers argue in favour of "redesigning the way society invests in innovation and looks at new ways of supporting a wider diversity of sites of innovation activity", pointing to both crowdfunding and public investment (Smith and Stirling, 2016).

At the same time, enablers and barriers to hybrid innovation are not necessarily financial but often linked to other motivations. Some scholars recognize multiple motivations (not only monetary, but also ideological or cooperative) in innovation (Warnke et al., 2016; citing Rifkin, 2014). A similar insight has also been applied to grass-roots innovations in India where intrinsic (for example, duty or dharma) motivations often play an important role in driving local innovation, but may be negatively affected by policies that focus on extrinsic (monetary support, rewards or patenting) motivations (Bhaduri and Kumar, 2011). Under such circumstances, the generation of a vision and the formation of a community of actors committed to shared goals enhance the possibility of innovation. Beyond this, non-monetary benefits, such as recognition through awards (raising the profiles of innovators and providing them with legitimacy or access to networks) can play a role.

While Governments are relatively new to some of the more novel financing approaches (see subsection 3.4.2), organizations such as the World Economic Forum and Ashoka and others have been using such approaches for many years. Key policy considerations, with regard to financing include the following:

- The choice of economic instrument used (for example, prizes and advance market commitments) and their design; this is a specialist task and bad design can lead to perverse incentives (see subsection 3.1.2)
- How to combine vertical and horizontal approaches to funding (Ooms et al., 2008). In the area of global health funding, for example, vertical financing can be described as aiming for disease-specific results and horizontal financing as aiming for improved health systems. A diagonal approach is defined as aiming for disease-specific results through improved health systems
- Opportunities for combining financing at a national level with other actors (see subsection 3.1.1)
- Processes for identifying the mission and ensuring that they are robust and respond to the priorities of multiple stakeholders (see section 4.3)

Regulation

Regulatory instruments can help to shift the direction of innovation towards the targets of the Sustainable Development Goals, support some of the emerging approaches or help stop industrial activities that are inconsistent with the Goals. Command and control policies (for example, technology imposing standards on polluting industries to incentivize the diffusion of cleaner innovation) or economic instruments (for example, pollution taxes and emissions trading) have long been used to induce innovation towards improved environmental performance (Berkhout and Gouldson, 2003; Porter and Van der Linde, 1995). Such approaches have been practised for many years alongside policies to support innovation systems. More recent work has shown how policy mixes, including economic instruments, regulations and information measures (which link to network facilitation) can combine to support innovation in the renewable energy industry (Rogge et al., 2015).

The distributed, multi-stakeholder nature of many new and emerging approaches to innovation necessitates new, additional forms of regulation that provide the conditions that will enable them

to flourish. Public procurement regulations that promote specific open (for example, creative commons) or mission-oriented (for example, linked to particular programmes) initiatives can act as demand–pull measures to support innovation with regard to the Sustainable Development Goals.

In science systems, regulating for open access online publications (rather than researchers being assessed, for example, on their production of copyrighted material) can enhance collaboration. Regulating against the appropriation of open data or knowledge is much more difficult, yet digital badges, for example, can offer a way for authors to mark their outputs (such as journal articles) as open (containing open data or materials) to signal their intention that it should be available for unrestrained use.

At the same time as such new regulatory approaches may be beneficial, old and outdated regulations, including inappropriate intellectual property frameworks, must be reformed. As traditional innovation systems display path dependency based on their historical developments, institutions and interactions may be locked in or overly bureaucratic, and act against the kind of fluid experimentation required for the new approaches. Public sector organizations must be willing to experiment with and directly involve beneficiaries (see section 3.5), requiring changes in organizational culture (Smith and Stirling, 2016), as well as bureaucratic systems.

4.2 Strengthening innovation capabilities

The innovation approaches described in this study are diverse. While they rely largely on similar innovation capabilities as traditional forms of innovation, some – in particular with regard to open digital collaboration – require new skills and infrastructures and benefit from different governance arrangements. This subsection outlines related considerations for national Governments.

Innovation capabilities involve not only scientific and technological capacity, but often, and more importantly in the context of developing countries, basic education, engineering, design and management skills (Bell, 2009). Examples from the Dominican Republic, Kenya and Nigeria show how public policy can strengthen education systems to build science, technology and innovation capabilities[17]. Research and development generates new knowledge that can be applied through innovation but does not drive it and, as such, investment in research and development, is unlikely to build innovation capabilities on its own. Instead, innovation capabilities come about as a result of investments across a range of skills areas and by processes of learning and interaction between innovation actors and across national borders (Lundvall et al., 2009). At the microlevel, entrepreneurship training can provide a valuable addition to the introduction of new products and services that aim to be pro-poor.

Open digital collaboration requires similar levels of basic education and scientific and technological literacy as more traditional forms of technological innovation. It is therefore difficult to imagine leapfrogging directly to such emerging innovation approaches. As discussed earlier, online training courses such as massive online open courses can contribute to overcoming such challenges.

Beyond this, ICTs are a cross-cutting area for policy support, and ICT infrastructure is a key consideration for developing countries, and Internet access and quality are incorporated within the indicators for Goal 17. Previous CSTD priority themes on Internet broadband for an inclusive digital society (UNCTAD, 2013) and digital development (UNCTAD, 2014c) cover these issues in detail. Beyond these, however, the increasing role of smartphones in online digital collaboration deserves further consideration. Recent research has shown vast differences across national contexts, as well as gender and age-related divides in the ownership and use of smartphones (Pew, 2016). Open connectivity beyond, as well as within, national boundaries is an additional requirement if a country's innovators are to effectively connect with collaborators and participate in North–South, South–South and South–North learning.

Capabilities are central for effective innovation, but are unevenly distributed across countries. Efforts should be made to identify and strengthen the required capabilities to innovate and to create enabling environments for innovation. Global initiatives aimed at providing technical assistance and sharing good practices in capacity-building are highly relevant. CSTD is well placed to serve as

[17] Contributions from the Governments of the Dominican Republic, Kenya and Nigeria.

a platform for promoting such initiatives. Country contexts, cultures and local needs are diverse when it comes to capacity-building for science, technology and innovation. Therefore, there is a need for Governments and various non-State actors to network and to create the capacity to adapt innovations to local contexts and cultures. For instance, developing countries, including the least developed countries, are characterized by a large informal sector and a high incidence of informal sector innovation, much of which is incremental in nature. Science, technology and innovation-related capacity-building in this context means supporting the large-scale deployment of existing technologies already in widespread use elsewhere, as well as experimenting with new innovation approaches.

4.3 Priority-setting with multiple stakeholders

Prior to the crafting of a mix of policy instruments as described above, a key governance challenge is agenda-setting and the identification of national priorities. Especially in circumstances of constrained resources, technically informed and politically robust methods of setting priorities across multiple stakeholders are a key requirement.

Broadening out inputs for such priority-setting by including multiple actors in the appraisal of sustainability options can lead to more empowering and robust policy approaches. With regard to STI, technology assessment and technology foresight are among the tools that can be used to identify priorities, with more networked and open approaches providing opportunities to simultaneously link up actors in extended innovation systems, both at national or international levels (Ely et al., 2011; Ely et al., 2014; Stirling et al., 2007; Van Zwanenberg et al., 2009).

While mission-oriented approaches require a degree of top-down management, the new and emerging approaches to innovation, in particular when enabled through open and digital collaboration, often require Governments to provide a platform through which other stakeholders can contribute. For example, the Indian Open Source Drug Discovery initiative is a platform provided by the publicly-funded Council for Scientific and Industrial Research that has enabled an evolving research and development portfolio, including on tuberculosis, malaria, and involving a diverse range of national and international partners from the research, university and private sectors (http://www.osdd.net). Thus, while identifying shared priorities is important, flexibility that allows different stakeholders to co-produce knowledge and shape the direction of innovation is a characteristic of such platforms.

Broadening out can also be hardwired into funding mechanisms such as crowdfunding. The Longitude Prize in the United Kingdom, for example, allowed the public to choose the projects to be funded, introducing a democratic component to prioritization and mission definition (see subsection 3.1.1). Providing funds through mission-oriented approaches, especially when it involves larger investments than usual, can come under additional scrutiny from users of social media and a more networked citizenry. The appropriate response is to embrace this openness (through open policymaking (see Totterdill et al., 2015) rather than attempting to constrain the flow of information or debate. However, this raises serious political as well as technical challenges for many developing countries (see section 4.5).

4.4 Embracing digitization as an enabler for new innovation approaches

Digitization of data is an enabler for new and emerging innovation approaches, yet digital development is not enough. Seeking, adopting and using knowledge and innovation requires human capital, market and non-market linkages and the kinds of capacity identified in studies of technological accumulation in developing countries (Bell and Pavitt, 1993). Thus, while increasing digitization is relevant to information flow and access, it is important not to lose sight of more traditional capabilities.

Digitization can be most powerful when it allows for the aggregation and disaggregation of data in order that it may be applied by various stakeholders addressing various goals to ensure that no one is left behind (Data Revolution Group, 2014). Yet beyond raw data and access, this requires protocols for sharing, and arrangements through which ownership and openness are governed. This can include licences (such as creative commons and copyleft) and other ways of ensuring that there are no free riders that extract and appropriate

the shared knowledge that is being generated. While such systems are becoming more and more sophisticated, further innovation in blockchain or distributed ledger technology, which can be used to track different contributions to shared knowledge, may further enhance the efficiency of sharing (Sierra, 2016). Others suggest that blockchain may be used as more efficient means to regulate intellectual property, facilitate the sharing economy or further opening up manufacturing (Tapscott and Tapscott, 2016).

Artificial intelligence and machine learning offer further opportunities for enhanced collaboration across databases. As shown in the e-bird example, artificial intelligence can potentially bring together diverse data sources to address complex problems that characterize certain aspects of the 2030 Agenda for Sustainable Development. At the same time, emerging technologies such as distributed ledger technology and artificial intelligence themselves raise questions about the distribution of the benefits, costs and risks of innovation (see section 4.5).

Digital collaboration offers huge potential, but it also raises challenges. As discussed in subsection 3.5.2, it is not always easy to translate open software processes to open science or open hardware. In addition, considerations remain about who can be involved and who cannot; much of the knowledge that is most relevant to the focus of the Sustainable Development Goals on basic needs (whether associated with food security, gender equality or peace) is tacit and cultural, not modular or granular (Benkler and Nissenbaum, 2006), and cannot be digitized. Active research and governance are required to ensure that such forms of knowledge are not crowded out by the increased attention and resources being allocated to digital approaches.

4.5 Governance challenges at national levels

While the Sustainable Development Goals are universal, specific priorities are set at regional, national and local levels through a combination of technical and democratic processes (Day et al., 2013). Coordinating efforts across the Goals and recognizing the interactions between them are a key challenge (Stevens and Nilsson, 2016). Some countries, such as Colombia and Sweden, have established cross-ministerial committees to map out a national strategy for the interacting Goals (Le Blanc, 2015) and researchers have developed a seven-point scale of interaction to aid this process (Nilsson et al., 2016). Rather than agenda-setting in sectoral isolation, this requires interaction across nexus issues such as energy, agriculture and water (Stirling, 2015), a diversity of innovation options (Stirling, 2009) and policy mixes to foster multiple outcomes (Rogge et al., 2016).

Skills for policy development and implementation (of both specialist and non-specialist policymakers) are lacking in many developing countries. This is important, as priorities and contexts differ from one country to another, and the choice of policy instruments and their design cannot be easily transferred. At the level of innovation systems, agenda-setting, financing, monitoring, evaluating and accountability will all be key considerations. Beyond innovation systems, complementary policies and regulations (see section 4.1) are required to steer innovation in directions that serve environmental sustainability and other objectives. Beyond implementation, processes for monitoring progress and adapting policies based on emerging evidence require another set of skills.

Monitoring, evaluation and accountability within innovation systems is complex. Scholarship on inclusive innovation (Chataway et al., 2014) and responsible research and innovation (Stilgoe et al., 2013) presents elements of a framework for guiding innovation systems towards societal goals, but more research and policy experimentation is required to understand how these might be applied in different contexts.

Within research systems, there are various approaches to changing incentives in order that knowledge produced is both useful for other stakeholders and accessible for their use. One aim of collaborative innovation approaches is to maximize bidirectional linkages between researchers and research users. For example, various altmetrics can allow for digital tracing of interactions between researchers and other stakeholders and, potentially, their impacts on the Sustainable Development Goals. While ways to measure the interaction between research systems and different users are emerging, the real challenge is in influencing the quality (rather than merely enhancing the quantity) of such interactions.

As noted in section 3.3, encounters between some of the new and emerging approaches (such as

grass-roots innovation) with formal research and innovation systems are difficult to govern, yet policy should aim to enhance a synergistic dynamic of mutual mobilization, rather than focusing on the insertion and appropriation of new approaches into formal structures (Fressoli et al., 2014). In many cases, this will require national Governments or intergovernmental organizations to support more pro-poor, inclusive and collaborative components of hybrids, if the Goals are to be realized (Ely et al., 2013). Preventing free riders, appropriation or de-skilling (for example, through the displacement of labour and productive employment) due to such innovation approaches requires clear but flexible measures that are driven democratically, rather than purely by markets. During such processes, all stakeholders have a key role in holding to account those who have influence over innovation policies.

Digital technologies themselves are playing an increasing role in such democratic processes, and allowing diverse constituencies to form political alliances worldwide. The pervasive nature and transformative potential of some of these digital technologies calls attention to issues related to governance. Research on these aspects of governing science, technology, innovation and the Sustainable Development Goals is required alongside the new wave of international initiatives, if the 2030 Agenda for Sustainable Development is to be realized.

4.6. Remaining challenges and focal areas for further research

It is evident that the implications of the new approaches detailed in this paper for STI policy are far from well understood. As such initiatives mature, efforts to improve the knowledge base are warranted to inform national and international policy. Internationally linked research-based organizations such as the Transformative Innovation Policy Consortium, are efforts in this direction (http://www.transformative-innovation-policy.net).

Achieving the 2030 Agenda for Sustainable Development will require strong collaboration and partnerships among all stakeholders. Organizing innovation transnationally requires a move towards global sustainability-oriented innovation systems (Altenberg and Pegels, 2012) and transformative change (Leach et al., 2012). A range of international actors and United Nations initiatives, including CSTD and the Technology Facilitation Mechanism, provide platforms to build such systems. A top-down approach is unrealistic and possibly undesirable. Therefore, the role of national Governments remains paramount. As they move from a focus on an innovation system for economic growth and productivity to one that aims to transform systems (through deep transitions) towards sustainable development (Schot and Steinmueller, 2016), traditional approaches to benchmarking innovation policies need to be updated. Rather than aspiring to a definition of the most innovative country, the universal 2030 Agenda for Sustainable Development requires an approach that recognizes the contributions that all States can make to the process of transforming innovation policy for sustainable development.

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