Potential Impacts of Technologies on Global Inequalities & Sustainable Development

- CRISPR
- GGE
- 3D printing
- geoengineering
- big data
- blockchain
- gender
- employment
- environment
- education
- wealth
- health

Jessie Breslau, Alessandro Caprini, Garima Chotani, Cecilia Consalvo, Max van Deursen, Blue Donaton, Wessel van Dorst, Lorena Esquivias, Chiara Fiorino, Jared Gambo, Shanel Khalid, Rabia Munsaf Khan, Sara Mancinelli, Marvin Leon Matheis, Linne van der Meulen, Cléa Montanari, Julie Romano, Anna Rossi, Corry Rothuizen, Citra Siaiglan, Aneeqah Tariq, Michelle Viera, Sofie de Wit
Potential impacts of technologies on social inequalities and sustainable development
Final Integrated Report - 16th December 2019

Authors:
Breslau, Jessica;
Caprini, Alessandro;
Chotani, Garima;
Consalvo, Cecilia;
Deursen, Max van;
Donaton, Blue;
Dorst, Wessel van;
Esquivias, Lorena;
Fiorino, Chiara;
Gambo, Jared;
Khaliq, Shanel;
Khan, Rabia Munsaf;
Mancinelli, Sara;
Matheis, Marvin Leon;
Meulen, Linne van der;
Montanari, Cléa;
Romano, Julie
Rossi Anna;
Rothuizen, Corry;
Siagian, Citra;
Tariq, Aneeqah;
Viera, Michelle;
Wit, Sofie de

Supporting Lecturers
Hendriksen, Astrid (WUR);
Lahsen, Myanna (WUR);
Sonnenfield, David (SUNY)

UN Contact Persons
Freire Junior, Clovis;
Roehrl, Richard

Disclaimer Notice:
The views expressed in this report do not necessarily reflect those of Wageningen University & Research and The State University of New York, nor the experts. Experts speak their own behalf and their views do not necessarily reflect the views of their institution.
Preface

The following report is a consultancy project for the United Nations Conference on Trade and Development (UNCTAD) and the United Nations Department of Economic and Social Affairs (UNDESA) by a collaborative group of 22 BSc, MSc, and Ph.D. students from Wageningen University and Research (WUR) and the State University of New York (SUNY). The report serves to provide insight into the impacts of frontier technologies on existing and new forms of social inequalities, as well as prospects for sustainable development with particular consideration for Sustainable Development Goals 8, 9, 10, 12, and 13. These goals focus on decent work and economic growth, innovation and infrastructure, reduced inequalities, responsible consumption, and climate action. The ability for these goals to be met are framed within the implementation of frontier technologies including CRISPR, 3D printing, blockchain, big data, and geo-engineering. Each technology, including its ramifications, is considered independently, however, the synthesis report provides a comprehensive overview of the interplay and reciprocity between and among said frontier technologies.
Acknowledgements

We would like to express our sincere gratitude to all of those that have played a role in the completion of this report. First of all, we would like to thank the Division on Technology and Logistics of the United Nations Conference on Trade and Development (UNCTAD) and the Division for Sustainable Development Goals of United Nation Department of Economic and Social Affairs (UNDESA) for giving us the opportunity to write this report. We are very grateful to Dr. Clovis Freire and Dr. Richard Alexander Roehrl for their support and valuable input throughout the process of this consultancy. Furthermore, we would like to thank Dr. Myanna Lahsen and Dr. Astrid Hendriksen of the Environmental Policy Group at Wageningen University and Research, and Dr. David Sonnenfeld of the State University of New York for their guidance, encouragement, and feedback throughout the entirety of this project. Additionally, we would like to thank the Flot Studio for the infographics. Last but not least, we would like to thank all of the consulted experts who took the time to share their valuable knowledge, insights, and opinions. Without them, this report would not have been possible.

The following figure presents an overview of the consulted experts by region; a more detailed list of experts can be found in the annex of each individual policy brief.
Executive Summary

This report, including the six policy briefs, provide policy recommendations on the anticipated effects of new technologies on existing forms of social inequalities, potential new forms of inequalities, and prospects for sustainable development. These technologies are: CRISPR, 3D printing, blockchain, big data, and stratospheric aerosol injection. The report addresses the nexus between these technologies and Sustainable Development Goals 8, 9, 10, 12, and 13, that focus on zero hunger, decent work and economic growth, innovation and infrastructure, reduced inequalities, responsible consumption, and climate action. Each policy brief targets a number of the aforementioned SDGs and also relates to the overarching topic of the report: inclusion.

Differing Perspectives on CRISPR in Agriculture looks at the anticipated effects of the technology on food security and environmental sustainability. Potential benefits and risks are looked at through potential inequalities. To understand the uncertain future of CRISPR, different perspectives from several stakeholders were analyzed. Regulation is highlighted as a major concern that prevents equitable global implementation of the technology. Additional roadblocks are knowledge gaps, proprietary ownership, and general public mistrust. To overcome these challenges focuses on safety research and transparency are recommended. Additionally, all choices should be informed through technological transparency guided by the Responsible Innovation Framework.

Human Germline Gene Editing: A Reassessment of the Parameters to a Moratorium addresses social, ethical, and sustainability issues associated with implementation of the technology. At present the technology is not considered safe and experts are still pushing for regulation before advancements can be made. Unregulated clinical trials could negatively impact different minority groups. As conversation in the media on GGE has circulated, issues of consent for future generations and the potential for designer babies have brought up ethical concerns. This brief aims to provide an accessible summary of the baseline ethical concerns GGE would present, including medical tourism, women's loss of bodily autonomy, and discrimination against disabled peoples.

3D Printing: A Paradigm-Changing Technology explores current adoption trends and examines the ways in which the technology can contribute to sustainable development. It investigates possibilities to embed circular and biobased economy principles in 3D printing manufacturing and makes suggestions to steer clear of alternative scenarios in which the technology develops in environmentally destructive ways. Moreover, the necessity to facilitate widespread adoption of decentralized manufacturing to low-income and marginalized communities is described, obstacles are identified, and policy recommendations to overcome them are made. Finally, a risk assessment is used to identify the most salient risks in the short, medium, and long term.

Blockchain Futures: Exploring the Effects on Global Inequalities proposes a framework to understand and manage uncertain, yet large systemic risks of blockchain on inequalities. These are examined through the development of four scenarios in which blockchain solutions within global supply chains and their impact on smallholders are used to illustrate risks and benefits. The scenarios identify inequalities in terms of access, design, and outcome. It has been found that the scenario ‘Techno Society’ has the highest potential to reduce inequalities. In trying to achieve this scenario, policymakers should actively steer towards an innovative environment in which blockchains can be used, managed, and created by everyone. Corresponding recommendations focus on public funding for start-ups, liberal regulation, free educational blockchain programs, and youth empowerment.

Towards Collaborative Digital Agriculture in the Developing World analyzes the current diffusion and adoption of this technology in the developing world, its potential impact on food security, economic growth and climate resilience, and the risks associated with its tendency towards multinational market monopolization. The movement towards an open-data ecosystem and the formation of Multi-Stakeholder Partnerships between the private sector, governments, and different sectors of civil society, such as farmers organizations, are identified as key leverage points that could steer towards a more inclusive development of this technology in the developing world.

Stratospheric Aerosol Injection (SAI): Potential Effects on Inequalities focuses on a globally debated and largely theoretical climate-altering technology. Due to potential global impacts of this technology and its potential side effects, some have pushed to ban its use while others see it as a workable and necessary means to overcome the climate crisis. Despite uncertainties, this study found a number of associated risks, primarily ones that have the possibility to degrade the environment or increase global North-South inequalities.
# Table of Contents

Preface .......................................................................................................................... 3
Acknowledgements ........................................................................................................ 4
Executive Summary ......................................................................................................... 5
Key Messages .................................................................................................................. 8
Synthesis Report ............................................................................................................ 9
Introduction .................................................................................................................... 9
Chapter 1. The Promise of Technology ......................................................................... 10
Chapter 2. Underlying issues ......................................................................................... 12
Chapter 3. Leverage Points ........................................................................................... 14
Looking Forward: Reduced Inequalities Within Reach ............................................... 16
Key Recommendations .................................................................................................. 17

BIBLIOGRAPHY .......................................................................................................... 19
Policy Briefs .................................................................................................................... 20

Differing Perspectives on CRISPR in Agriculture ......................................................... 21

BIBLIOGRAPHY .......................................................................................................... 26
ANNEX I. CONSULTED EXPERTS ............................................................................. 28
ANNEX II. GLOSSARY ................................................................................................. 29
ANNEX III. METHODOLOGY ..................................................................................... 30
ANNEX IV: CASE STUDY ............................................................................................ 31
ANNEX V: CRISPR-DEPENDENT INEQUALITIES ................................................... 32

Human Germine Gene Editing ....................................................................................... 33

BIBLIOGRAPHY .......................................................................................................... 38
ANNEX I. CONSULTED EXPERTS ............................................................................. 39
ANNEX II. METHODOLOGY ....................................................................................... 40
ANNEX III. RISK ANALYSIS ..................................................................................... 41
ANNEX IV. INTERNATIONAL PERSPECTIVE ............................................................ 42

3D Printing ..................................................................................................................... 43

BIBLIOGRAPHY .......................................................................................................... 48
ANNEX I. CONSULTED EXPERTS ............................................................................. 50
ANNEX II. GLOSSARY ................................................................................................. 51
ANNEX III. METHODOLOGY ..................................................................................... 52
ANNEX IV. THE BASICS OF 3D PRINTING ............................................................... 52
ANNEX V. A LIST OF DRIVERS OF AND BARRIERS TO 3DP ADOPTION ................. 53

Blockchain Futures ....................................................................................................... 54

BIBLIOGRAPHY .......................................................................................................... 59
ANNEX I. CONSULTED EXPERTS ............................................................................. 61
<table>
<thead>
<tr>
<th>Annex</th>
<th>Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>II.</td>
<td>GLOSSARY</td>
<td>62</td>
</tr>
<tr>
<td>III.</td>
<td>METHODOLOGY</td>
<td>63</td>
</tr>
<tr>
<td>IV.</td>
<td>DRIVING FORCES DEFINITIONS</td>
<td>64</td>
</tr>
<tr>
<td>V.</td>
<td>DIAGRAMS</td>
<td>65</td>
</tr>
<tr>
<td>I.</td>
<td>CONSULTED EXPERTS</td>
<td>74</td>
</tr>
<tr>
<td>II.</td>
<td>GLOSSARY</td>
<td>75</td>
</tr>
<tr>
<td>III.</td>
<td>METHODOLOGY</td>
<td>76</td>
</tr>
<tr>
<td>IV.</td>
<td>OPEN DATA SPECTRUM</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td><strong>Big Data in Agriculture</strong></td>
<td>68</td>
</tr>
<tr>
<td></td>
<td>BIBLIOGRAPHY</td>
<td>73</td>
</tr>
<tr>
<td>I.</td>
<td>CONSULTED EXPERTS</td>
<td>74</td>
</tr>
<tr>
<td>II.</td>
<td>GLOSSARY</td>
<td>75</td>
</tr>
<tr>
<td>III.</td>
<td>METHODOLOGY</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td><strong>Stratospheric Aerosol Injection</strong></td>
<td>78</td>
</tr>
<tr>
<td></td>
<td>BIBLIOGRAPHY</td>
<td>83</td>
</tr>
<tr>
<td>I.</td>
<td>CONSULTED EXPERTS</td>
<td>85</td>
</tr>
<tr>
<td>II.</td>
<td>METHODS</td>
<td>85</td>
</tr>
</tbody>
</table>
Key Messages

Differing Perspectives on CRISPR in Agriculture

- A focus on minor, staple, and native Indigenous crops only enhances equality if this is something that relevant communities desire.
- Assumptions cannot be made by external third-parties as to what is beneficial for farming communities or smallholder farmers.
- When considering food security it is essential to reflect on food sovereignty and what constitutes autonomy.
- Open source and easier access to CRISPR technology can only be seen as promoting equality if such access provides equal opportunity for all parties.

Human Germline Gene Editing: A Reassessment of the Parameters to a Moratorium

- Human germline gene editing, in its early stages, is currently not safe enough for clinical trials.
- Moving forward with GGE technology needs to consider ramifications on minority groups, as they will be impacted the most (specifically women, disabled bodies, and the global south).
- Many experts called for a moratorium, though regulation beyond this is fraught with debate.
- Discussion must be had with a larger community to determine if and how the technology will move forward.

3D Printing: A Paradigm-changing Technology

- In developed countries, 3D Printing is either an industrial application or a “niche and hobby.” Conversely, 3D Printing has the potential to be transformative for all developing countries.
- 3D Printing offers a sustainable alternative to industrial manufacturing due to the supply chain decentralization and circular economy.
- 3D Printing could exemplify a leapfrogging technology for developing countries.

Blockchain Futures: Exploring the Effects on Global Inequalities

- The future of blockchain is highly uncertain and outcomes of different driving forces influence its impact on inequalities.
- Continuing business as usual is most likely to lead to an undesirable future.
- Policymakers are able to influence the future development of blockchain, described scenarios and recommendations give guidance to do so.
- Targeted measures and risk mitigation strategies should, therefore, be timely implemented.

Big Data: Towards Collaborative Digital Agriculture in the Developing World

- Digital agriculture is expected to impact food security, economic growth, and climate resilience in the developing world.
- The lack of infrastructure, digital data, coordination of private and public efforts, and reluctance to share data limits the diffusion of this technology in the developing world.
- The tendency of data technologies to favor market monopolies threatens to create a dependency of developing countries on developed countries and leads to unequal access to the benefits of technology.
- The movement towards open data and the inclusion of smallholder farmers in the development of the technology could mitigate certain risks by stimulating the local economy and ensuring bottom-up, need-driven innovation.

Stratospheric Aerosol Injection (SAI): Potential Effects on Inequalities

- SAI has the potential to lower global average temperature.
- The changes in climate while reducing temperature could have adverse effects on inequalities.
- Changes in precipitation could exacerbate North-South inequalities.
- The lack of governance surrounding the technology can be examined using the five Oxford Principles.
Synthesis Report

Introduction

Since 1980 inequalities have risen globally at different speeds and large disparities between the developed and developing worlds still remain. For instance, while some countries have reduced the percentage of people living in extreme poverty, the gap between rich and poor has increased: 1% of the global population owns 45% of the wealth worldwide. With the global population increasing, disparities are becoming more evident as access to food, water, healthcare, and education continue to grow, leaving the poorest and the most marginalized even farther behind. Moreover, climate change is increasing the magnitude of natural disasters such as droughts, floods, and hurricanes, leading to sea-level rise, biodiversity, and food loss. These hazards will have the most severe impacts on the poorest and most vulnerable populations of the world, thus further increasing inequalities.

Urgent and substantial actions are needed to overcome present and anticipated future challenges and create pathways towards a more sustainable and inclusive society. In this regard, frontier technologies hold great hope to help achieve a more sustainable future, as they promise to achieve invaluable goals, ranging from environmental sustainability and food security to combating diseases. While technological development has helped improve the lives of many over the past decades, hundreds of millions of people are still left behind, unable to fully reap the benefits that these technologies hold for human development. For this reason, this report considers inclusion as the main unifier of the following policy briefs.

The synthesis report will further examine the promises of the aforementioned frontier technologies and their interlinkages to the common Sustainable Development Goals (SDGs) identified throughout the policy-briefs, namely: SDG 8, 9, 10, 12 and 13. It will also provide a discussion on the underlying issues that characterize these technologies and analyze key leverage points that will influence their future development. Lastly, the synthesis report will conclude with final remarks on how to proceed, including lessons learned throughout the research process and recognition of its limitations.

This report aims to present a thorough analysis of the anticipated effects of new technologies on existing forms of social inequalities, potential new forms of inequalities, and prospects for sustainable development.

* INEQUALITIES: In this report, inequality will be defined as "the state of not being equal, especially in status, rights, and opportunities" (UN, 2015).

** TECHNOLOGIES: In this report, new frontier technologies will be defined as "those technologies that are innovative and fast-growing and have the potential to exert a significant impact on societies, economies and the environment" (Rotolo, Hicks and Martin, 2015). For the matter of this report all the present technologies will be considered as frontier technologies.
Chapter 1. The Promise of Technology

In 2015, the 2030 Agenda for Sustainable Development was adopted by the UN Member States, and 17 SDGs were created as a blueprint to leave no one behind in the pursuit of sustainable development. With ten years left, frontier technologies could accelerate the achievement of the Agenda by fostering growth, prosperity and environmental sustainability. Frontier technologies can help in eradicating hunger, reducing carbon emissions, creating decent jobs and enhancing economic growth, thereby making sustainable development a reality. Such technologies could therefore be instrumental in tackling current global challenges such as climate change and increasing inequalities. Similarly, frontier technologies could offer a window of opportunity for low-income and least developed countries to catch up, for example by leapfrogging socio-technical systems (e.g. transport, energy, water, communications).

The nexus between SDGs and science policy briefs

The technologies discussed in this report present substantial opportunities for the achievement of several key SDGs. This section will illustrate the main SDGs addressed within the policy briefs and will give a description of how each policy brief may contribute to the achievement of these sustainable development goals.

Figure 1 The nexus between SDGs and the six policy briefs.

Every line represents the extent to which every SDGs is addressed by the combination of all policy briefs.

Differing Perspectives on CRISPR in Agriculture

CRISPR technology has the potential to grow more nutritious, robust, and high yielding crops, addressing food security for the world’s most vulnerable populations (SDG 2). Additionally, CRISPR-edited crops may be able to be grown in previously uncultivable conditions such as drought and high salinity (SDG 15). The cultivation of more drought resistant staple crops such as rice, wheat, and corn can strengthen climate resilience and adaptive capacity of smallholder farmers in relation to climate related hazards (SDG 13). Through transparent technology, farmers and consumers can better understand the environmental, social, and economic impacts of their choices and make informed decisions (SDG 10, SDG 12).
Human Germline Gene Editing: A Reassessment of the Parameters for a Moratorium

GGE has the potential to prevent the transmission of rare and life-threatening diseases such as cancer and HIV across generations. This directly relates to SDG 3 which aims to achieve good health and well-being. However, gene pool data is often lacking in the developing world, leaving these communities relatively absent from gene editing technology research. Further research and proper regulation would be needed for GGE to help reduce inequalities, to ensure the technology is helping those most in need (SDG 10). Safeguards for affected minority groups for technology implementation will help improve inequalities. This is the same for gender equality (SDG 5). Women, the prime research targets for GGE, need to be incorporated in further discussions about the future of GGE. Their perspectives, as well as those of other underrepresented groups, will help mold the landscape of GGE technology and its regulation to help to eliminate inequalities.

3D Printing (3DP): A Paradigm-changing Technology

3D Printing technology has the potential to provide decent work and economic growth (SDG 8) through the adoption of 3DP to decentralize manufacturing. Moreover, it has the potential to contribute to industry, innovation and infrastructure (SDG 9), and responsible consumption and production (SDG 12) by replacing environmentally impactful transboundary supply chains with local and more eco-efficient ones. Other SDGs that are targeted indirectly are: Reducing inequalities (SDG 10), Sustainable Cities (SDG 11), Climate Action (SDG 13); and Partnerships for the goals (SDG 17).

Blockchain Futures: Exploring the Effects on Global Inequalities

Blockchain has the potential to contribute to the achievement of several SDGs such as decent work and economic growth (SDG 8), improved innovation and infrastructure (SDG 9), reduced inequalities (SDG 10), and responsible consumption and production (SDG 12). Depending on the information being stored, blockchain applications could enhance transparency in supply chains, increase efficiency of business processes, and promote inclusive growth. If widely and fairly applied in global supply chains, blockchain can lead to technological upgrading, formalization of enterprises, and financial inclusion and innovation. The implementation of blockchain solutions will go hand-in-hand with increased access to ICT and foster smallholder inclusion. The impact on the SDGs depends highly on which of the four future scenarios discussed in the policy brief plays out and how it can be steered by policy makers.

Big Data: Towards Collaborative Digital Agriculture in the Developing World

The use of digital technologies based on data collection in agriculture holds great potential to contribute to Sustainable Development. Due to higher agricultural yields and improved efficiency throughout the value chain, this technology promises to play a big role in hunger eradication and food security (SDG 2). It is also expected to boost economic productivity and growth, while at the same time create demand for high-skilled workers in the agritech sector and stimulate entrepreneurship and creativity (SDG 8). Finally, the services provided by digital agriculture could play an important role in building climate-resilient societies in the parts of the world that are most affected by climate change (SDG 13). However, these benefits are threatened by the tendency of data-technologies to evolve towards market monopolies. Strong and inclusive partnerships will be necessary to ensure equal spread of the benefits (SDG 17) and hereby contribute to the reduction of inequalities (SDG 10).

Stratospheric Aerosol Injection (SAI): Potential Effects on Inequalities

Reduced Inequalities (10) - In terms of reduced inequalities SAI can go either way. Currently climate change is causing increased inequalities, especially for less developed nations who tend to be the most affected, through changes in weather and loss of land that creates climate refugees and effects economic systems. Since SAI can potentially contrast sea level rise, it has the ability to reduce the inequalities being created by preventing displacement and damage caused by increased storm damage along the coast where 40% of people reside.
Chapter 2. Underlying issues

The rapid development of frontier technologies increases the likelihood of exacerbating existing inequalities and creating new inequalities. Therefore, it is essential to understand the changes brought about by different technologies in favor of society, the environment, and the economy. In this regard, three underlying main issues that could enhance the risks of the technologies and their disruptive nature have been identified throughout the different policy briefs: power centralization, path-dependence, and perception of technology as a ‘silver bullet’.

**Power Centralization**

Power centralization in the development of technologies is crucial, as the majority of the intellectual property, financing, development, and benefits of technologies are concentrated in the developed countries, often in the hands of a few private actors. This not only implies proprietary access and limited accessibility for certain nations or actors, but also has the potential to create bias and skewed benefits through a lack of transparency and retention. The power to develop technologies is likely to be increasingly centralized, as frontier technologies often rely on digital data. Products relying on digital data often benefit from the Network Effect, meaning that they become more valuable the more users they have, resulting in a positive feedback loop. Those who control the data therefore have a competitive advantage, which might result in an uneven playing field with few winners and many losers.

**Path dependence**

Path dependence is a phenomenon that illustrates how the current range of possibilities one faces is limited by choices one has made in the past. Alternative paths of action become increasingly less likely over time as irreversible decisions are made and learning and coordination effects occur. As a result, a positive feedback mechanism can be set in motion which may result in a lock-in of a certain situation, regardless of whether that situation is efficient or desirable. The concept of path dependence has been specifically used to explain how certain technologies might be able to assume a dominant position in the market and be almost completely unassailable in their position, even though new and better technologies may develop. Path dependence raises important challenges in the face of increasingly severe climate change issues and growing inequalities worldwide. Despite their efforts, many developed, high-income countries are restricted in reducing their emission by the high costs of switching from high to lower carbon-intensive energy sources. Similarly, many developing countries are designing low-emission development strategies, while they are at the same time on a course of investment that is locking them into high-emission infrastructure.
Technology as ‘silver bullet’

A ‘silver bullet’ can be defined as a solution that cuts through the complexity of a problem and provides a complete and immediate solution to it. Although technologies play an important role in addressing issues such as climate change, they cannot be viewed as such. Many problems we face today have deep social and economic roots and technologies have limited ability to solve them. Viewing technologies as a ‘silver bullet’ can be problematic since technologies often do not address these core causes. For example, CRISPR technology can help farmers cope with climate change by developing drought-resistant crops, but it does not address the underlying issue of increasing droughts as a result of climate change. Similarly, blockchain is able to enhance transparency and help promote sustainable production and consumption patterns, but will only be able to do so if other fundamental issues such as political will, incentives for farmers, and willingness of consumers to pay more for sustainable products are also addressed. Viewing technology as a ‘silver bullet’ to current issues such as climate change and growing inequalities has the risk of shifting the attention away from the root causes of these issues.
Chapter 3. Leverage Points

The 2030 UN Agenda has recognized that failing to improve the lives of those furthest behind will not only increase inequalities, but also hinder the achievement of the SDGs. Additionally, the UN stated that, “in order to eradicate poverty and reorient current unsustainable development trajectories, affordable technological solutions have to be developed and disseminated widely.” Therefore, the impact that new frontier technologies will have on existing and future inequalities is likely to be influenced by a key driving force: inclusion. Inclusion has been identified as the common key driver of each frontier technology discussed in this report, recognizing the fact that it will play an important role in determining whether technologies will benefit or hamper the effort to promote equality and sustainable development.

Given the socially exclusive nature of most contemporary innovation trajectories, new innovative approaches are essential for the transition towards a more sustainable and inclusive society. In this sense, the Ladder of Inclusion can help introduce new frontier technologies into the global society by applying more inclusive and representative measures. More specifically, the Ladder of Inclusion identifies six levels of inclusion that will play an important role in shaping the future development of these technologies and their related impacts.

As depicted in Figure 3, the steps of the Ladder are numbered from one to six and every succeeding step represents a broader notion of inclusion. This way, the greatest level of inclusion (level 5 and 6) is reached once the first four levels have been implemented. However, because of the deep rooted and structural nature of the underlying issues presented in Chapter 2, this is not the case for frontier technologies. Underlying issues are so embedded in the innovation process, that if they are not addressed first, they will hamper the potential of frontier technologies and enhance their related risks. As a result, going from bottom to top is likely to be ineffective, since levels one to four do not directly tackle the underlying issues. In this regard, since levels five and six refer to the Inclusion of Structure and Post-structural Inclusion, implementing these levels first will ensure that underlying issues are addressed as well (as the reversed Ladder of Inclusion depicts in Figure 4). Therefore, the achievement of all six levels seems to rest on the broader foundation of levels five and six.
In order to reach the new starting point of the reversed Ladder of Inclusion, level five and six, a system change is required, for which leverage points are difficult to identify. Nevertheless, it is relevant to examine the key leverage points that will influence each of the remaining levels.

**Level 1** refers to the Inclusion of Innovation. A key leverage point that will highly influence whether innovators will intend to make their technology more inclusive is related to whether institutions under which innovators work will place the achievement of SDGs higher in their agenda.

**Level 2** refers to the Inclusion of Consumption. Key leverage points which will highly influence whether innovation will be adopted and used by marginalized groups are: digital divide and lack of infrastructure, such as electricity and internet. For instance, the digital divide is a major roadblock to the accessibility of digital technologies in many developing countries.\(^\text{14}\)

**Level 3** refers to the Inclusion of Impact. Key leverage points that will highly influence whether the benefits of frontier technologies will be accessible to the marginalized groups are: capacity building and problem-based innovation. Capacity building is not only about the knowledge and skills needed to use technology effectively, but also about how to protect oneself from certain technological risks, such as scams. Problem-based innovation refers to innovation and design of technologies that address specific problems experienced by marginalized communities. Often a technology is designed for marginalized communities in a way that does not match their needs.

**Level 4** refers to the Inclusion of Process. Key leverage points that will influence how technological innovation will be adopted by different groups include: partnerships and regulation. Including marginalized communities in the process of developing and designing technologies can be achieved through multi-sectoral partnerships. The concept of multi-sectoral partnerships spans a wide and diverse array of institutional arrangements for expanding collaborations between governments, businesses (and other private sector actors), civil societies, and other multilateral agencies to address sustainable development challenges.\(^\text{15}\) If all stakeholders are involved, partnerships will be able to build synergies and leverage their core knowledge, skills, resources, and assets in such a way to create solutions that none of the partners could have developed on their own. If marginalized communities are involved in the process of designing and developing technologies, they will be more likely to benefit from them. Regulations can furthermore be established that promote innovation processes in developing countries and assist in reducing the innovation divide.
Looking Forward: Reduced Inequalities Within Reach

This report has so far assessed how frontier technologies, including CRISPR, 3D printing, blockchain, big data, and stratospheric aerosol injection will affect inequalities. It has illustrated that in order to harness the potential of frontier technologies for sustainable development and ensure inclusive innovation, business-as-usual will not suffice. Policy makers must actively take a stance and implement measures that steer these technologies to a desirable direction. In terms of actions, there is no one-size-fits-all approach, yet this synthesis report has identified certain overarching principles.

This report identifies power centralization, path dependence, and perception of technology as a ‘silver bullet’ as underlying issues. These enhance and reinforce the risks of the technologies to contribute to inequalities. The ladder of inclusive innovation provides a framework to address these underlying issues. Each policy brief addresses how multi-sectoral partnerships are key to ensure an inclusive process of innovation. An orientation towards problem-based innovation, in combination with capacity building, ensure that the benefits of innovations are widely disseminated. Addressing the digital divide and infrastructure barriers by providing universal electricity and internet access could ensure that the technologies reach those who are still left behind.

The coming years will be pivotal in steering these frontier technologies in a direction that benefits all. The longer action is delayed, the more difficult it will become to alter the trajectories of technologies. This report aims to provide policy makers and stakeholders with a general understanding of the aforementioned frontier technologies and the tools to effectively manage innovation in a way that benefits society. Reduced inequalities are within reach.
Key Recommendations

Differing Perspectives on CRISPR in Agriculture
- Safety research should be funded by the public sector.
- CRISPR technology should be used to edit crops to enhance climate adaptivity not to increase herbicide resistance.
- International labelling regulations to ensure market transparency.
- CRISPR research should focus on minor and staple crops to contribute to food security and food sovereignty.

Human Germline Gene Editing: A Reassessment of the Parameters to a Moratorium
- Backing of moratorium by international and national governing bodies to give time for decision-making process.
- Participatory processes should bring together experts, policy makers, and the public. Underrepresented voices of women, people of color, the disabled community, and the Global South need to be included in discussion.
- Research on human germline gene editing should have strict parameters for performing research and safeguard women participating in clinical trials.
- Technology should remain non-privatized and improve investment in Global South gene banks to further research on ethnically diverse genetic information.

3D Printing: A Paradigm-changing Technology
- Enable a waste management system and incentivize circular economy, alongside considering the further possibilities for bio-based materials.
- Facilitate partnerships among different stakeholders in order to ease the adoption of 3DP through a multi-level decision making process.
- Contextualize the adoption of 3DP to specific needs. Different contexts have different problems, hence 3DP can provide different solutions. Policy makers must be aware of the several possibilities of 3DP and enable capacity development.
- Adopt a flexible approach towards the 3DP possibilities for the improvement of basic needs.

Blockchain Futures: Exploring the Effects on Global Inequalities
Policy makers should actively steer towards a highly innovative environment in which blockchains can be used, managed and created by everyone. This can be done by implementing the following measures:
- (Inter)national and regional government entities should allocate funding to innovative start-ups and SMEs.
- National and regional government entities should adopt liberal and innovative regulation, including regulatory sandboxes that allow for experimentation.
- Educational institutions and national governments should make blockchain an integral part of education curricula. Moreover, online learning programs focusing on blockchain should be made freely available for the public.
- Empower youth, especially from developing countries, to participate in blockchain development by making them a focal point in each of the measures stated above.

Big Data: Towards Collaborative Digital Agriculture in the Developing World
- With regards to needs driven innovation and empowerment of farmers, the United Nations and government sectors should consider stimulating farmer-centric multi-sectoral partnerships in digital agriculture.
- In order to increase local economic activity and the diversity of information, the United Nations and governments should aim to stimulate the sharing of data.
- In order to avoid the exploitation of sensitive data, governments should consider developing a legislative framework for the selective sharing of data and increase transparency of data usage.

Stratospheric Aerosol Injection: Potential Effects on Inequalities
- Use of the five Oxford principles to determine best policy about SAI implementation.
- Promote safe and controlled research so that more informed decisions can be made about whether or not to implement SAI. Research will help better predict which areas will be most affected.
- Promote other climate mitigation methods aside from SAI, such as a decrease in fossil fuel dependency.
» Provide incentives for using renewable energies. This will aide in helping problems which SAI does not address such as ocean acidification and air quality.

» Global consensus is needed. The decision to implement SAI will have global effects and areas which are most affected must have as equal of decision making as powerful leaders.

2. SDGs. (n.d.). Goal 10: Reduce inequality within and among countries.


Policy Briefs

Differing Perspectives on Crispr in Agriculture
Impacts on Food Security and Environmental Sustainability

Human Germline Gene Editing
A Reassessment of the Parameters to a Moratorium

3D Printing
A Paradigm Changing Technology

Big Data in Agriculture
Towards Collaborative Digital Agriculture in the developing words

Blockchain Futures
Exploring the Anticipated Effects of Blockchain on Inequalities

Geo engineering
The Many Stakeholders and Effects of Stratospheric Aerosol Injection
APPLICATIONS OF CRISPR IN AGRICULTURE

INTRODUCTION
The agricultural sector is not only affected by climate change but is also one of the largest contributing industries of greenhouse gas emissions. By shifting to more sustainable and resilient agricultural practices this sector can also hold part of the remedy to climate change. Currently, hunger and malnutrition affect over 820 million people globally, with world population anticipated to increase to 9 billion by 2050. Such statistics imply that agriculture is, and has been, at a crossroads as threats of climate change, rapid population growth, and increasing social inequalities further exacerbate food insecurity and the need for a new solution. Recent advancement and research show that CRISPR has the potential to mitigate and enhance said problems through the production of crop varieties with higher yield potential, biofortification, enhanced abiotic stress tolerance, and improved resistance to major pests and pathogens. Regulation is highlighted as a major concern that prevents equitable global implementation of the technology. Additional roadblocks to be considered are knowledge gaps, proprietary ownership, and general public mistrust. To overcome these challenges focuses on safety research and transparency are recommended to be guided by the Responsible Innovation Framework. This policy brief looks at the anticipated effects of CRISPR technology on food security and environmental sustainability with the aim of better understanding necessary and viable solutions.

WHAT IS CRISPR & HOW IT WORKS
CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats) is a bacterial defense system against invading viruses. After the discovery of the mechanism in the period between 1987 and 2012, CRISPR-Cas9 was developed into a new gene editing technique in 2012 that can alter the DNA sequences of humans, animals, and plants. Cas9, one of the many proteins that uses CRISPR sequences in bacterial species, acts like a pair of molecular scissors that cuts DNA strands at a specific location and activates the cell’s natural DNA repair mechanism. By introducing a foreign DNA template, this repair mechanism can be exploited to introduce desired changes.

APPLICATIONS OF CRISPR IN AGRICULTURE

CRISPR technology has the potential to be applied in agricultural crops by altering genes for desired traits like high yields, enhanced quality, hybrid varieties, and disease resistance. Several proposed applications are:

- Pest resistance
- Drought resistance
- Increased longevity
- Improved nutrition

POTENTIAL BENEFITS

Food Security
The Food and Agriculture Organization (FAO) defines four dimensions of food security: availability, access, utilization and stability. Additionally, nutrition is fundamental within the concept of food security. Nutritional security is embedded in the concept of food security and designates access to food, care and feeding, and health and sanitation as essential targets.

Cereals form a major part of the human diet, with their utilization expected to increase in the future. CRISPR technology has conferred resistance to varied diseases in wheat and rice and has fortified nutritional quantities. If CRISPR can be tested and safely implemented outside of the laboratory it may very well have a major role in addressing food availability.

Agri-dependent Livelihoods
Access to technology largely determines its impact on the livelihoods of smallholder farmers. Technology is often accepted by farming communities if it aligns with their basic needs, is affordable, and fits within existing traditional farming practices. Societal encouragement and engagement are important for the adoption of new technologies and help shape technological perceptions based on risks and benefits through the consideration of ethical and scientific concerns.

Environmental
- Efficient Water Use
- Improved Nitrogen Fixation
- Control of Invasive Species
- Improved Soil Health
- Better Land Use

POTENTIAL RISKS AND UNINTENDED EFFECTS

Tech-related Risks
Although CRISPR can modify an organism through more precise DNA cuts, the risk of off-target mutations that cause genomic instability and disrupt the functionality of

KEY MESSAGES
- A focus on the minor, staple and native Indigenous crops only enhances equality if this is something that relevant communities desire
- Assumptions cannot be made by external third-parties as to what is beneficial for farming communities or smallholder farmers
- When considering food security it is essential to reflect on food sovereignty and what constitutes autonomy
- Open source and easier access to CRISPR technology can only be seen as promoting equality if such access provides equal opportunity for all parties
otherwise normal genes is still high. Research has also shown risks of large unintended deletions of DNA, genetic rearrangements, and uncontrollable proliferation. These alterations in DNA have the potential to negatively affect human health and food and environmental safety, meaning there is still need for more research on the short and long-term safety of gene-edited products.

Environment-Related Risks

**Insects**
When released in the field, CRISPR-edited crops could have negative consequences on insect populations, potentially diminishing biodiversity. A decline in pollinators, for example, poses potential hazards to food production and food security. Such risks could arise when prospective impacts are only analyzed considering a single plant and not framed in the larger context of the ecosystem in which it will be grown.

**Plants**
Altered DNA could be transferred between organisms by vertical or horizontal gene transfer from CRISPR-edited crops to native varieties. It is possible that CRISPR-edited crops may unintentionally introduce alien DNA through cross-pollination, meaning that wild crops and landraces could be contaminated by CRISPR-edited crops, leading to a potential loss of certain traits of traditional and native varieties.

**Agri-Dependent Livelihoods**

**Herbicide-Tolerant CRISPR-Edited Plants**
Herbicide-resistant crops as a single means of weed control is an insufficient and environmentally harmful agricultural practice. Looking at past examples, it is likely that if CRISPR is applied to create herbicide-resistant crops, there is a high chance it will significantly reduce biodiversity and negatively impact weed management and agricultural practices such as crop rotation and diversification, and could encourage reliance on external inputs. For this reason, there is concern that CRISPR might further entrench a chemical-intensive approach to agriculture.

**Genetic Vulnerability and Crop Diversity**
CRISPR technology could further impoverish agrobiodiversity if investments are only concentrated on a few crop varieties. The advent of biotechnology facilitated monocultures in ways that were not possible before. Monocultures usually increase plant pathogens and diseases, soil degradation, and water waste, which ultimately undermines food production in the long term and could result in crops not suited to cope with emerging climate patterns.

**REGULATION**

**Present Situation**
Currently, there is a lack of international consensus regarding the regulation of gene-editing technology, including that of CRISPR. This dearth of international regulation is in part derived from the absence of overarching national dictate. Within the EU CRISPR-edited crops are regarded as GMOs and are subject to the same regulations. Conversely, in the United States there is no regulation on gene-edited crops when foreign DNA is not found in the final product, meaning that such products can be put on the market free of labels. The US regulatory process is based on the evaluation of the final characteristics of the variety to be brought on the market, while EU regulation is based on the methods used in the process. If a US producer wants to export their CRISPR-modified crop to Europe they must comply with EU regulations and labeling system. Canada is the country with the most consistent legislation: any plant variety with a trait that may be considered as ‘novel’ is scrutinized; this concerns all varieties regardless of the methods used in the breeding process. Additionally, South Africa currently has labeling regulations for GMO foods, yet it is unclear if CRISPR edited crops will fall under this category, meaning that they may avoid labelling regimes and transparency.

**Present Concerns**
Regulation cannot keep pace with innovation. This is evident on both national and international levels. International guiding principles are essential to reach key common goals such as food and environmental safety. Currently the Cartagena Protocol clarifies trade regulations regarding GMOs, yet it does not define specific global regulations regarding proper use-cases to protect people and the environment from harm. This lack of authoritative international governance brings up concern surrounding trade and transparency in labelling as countries with lax or no regulation on gene-edited crops may be capable of infiltrating markets that have strict regulations or bans. Additionally this brings up concerns regarding freedom of choice and ethics for end users.

**Future Concerns**
Consumer demands are shifting. Organic food consumption is on the rise and it is expected that consumers will also have increased demand for sustainably and locally produced food, which begs the question: are CRISPR-edited crops what consumers are looking for? Not only must CRISPR technology be evaluated for safety, but also for consumer desirability. The role of regulation and patents will determine the accessibility and democratization of CRISPR, as well as the function of monopolies. Regulation should be looked at through distinct national and international lenses, yet it is essential to recognize that national and regional regulations have the power to impact international markets and agricultural practices. Although safe implementation of the technology is of concern for all nations, the threat of food insecurity is heavily concentrated in developing countries, meaning that the reasoning behind CRISPR implementation varies greatly within continents and among nations. This is not to suggest that there is no common ground. Albeit for different reasons and to different extents, climate change, food security, and environmental safety are overarching concerns of all involved parties. Additionally, the concept of agency and sovereignty must be considered in the arguments for, or against, CRISPR to ensure that the needs of all nations are best supported.
DIFFERING OPINIONS

Natural & CRISPR Scientists

A portion of the scientific community does not consider CRISPR a dangerous technology because it makes targeted alterations, resulting in fewer unintended effects than alternative methods. Additionally, some scientists claim that CRISPR-edited crops will not have serious consequences for human health nor the environment since CRISPR can modify plants without inserting foreign genes, creating mutations that could have also been achieved naturally. Conversely, others highlight significant challenges for successful utilization of CRISPR. Firstly, there exists limited understanding of gene function on the type of modification required to bring the desired change. Secondly, crossing between edited and unedited plants can cause reversion to wild-type phenotypes. Scientists working with CRISPR technology highlight the knowledge gap between the scientific community and the public as a main roadblock to CRISPR implementation in the agricultural sector, as it hinders public understanding and could promote fear of CRISPR.

Social Science & Ethics

Ethical and safety concerns are rising globally surrounding the application of CRISPR. Who has access to the technology? Who benefits? Who will become more vulnerable from its adoption? And are the benefits related to the technology greater than the risks? The unforeseen effects resulting from CRISPR are the foundation of the current debate around its implementation. Social scientists fear that gene-edited organisms may have different effects in natural environments than in the laboratory, as they feel it is unfounded to fully trust a technology that has only been implemented in labs. Prior to implementation, there is a need to assess new crops through field trials based on its environmental and food safety. This raises existential doubts about safety which therefore mars public perception. Additionally, there is concern that centralized access to the technology will most likely enhance disparities and inequalities.

Smallholders

Farmers are not a homogenous entity and therefore have different needs and concerns regarding food security issues, particularly those that grow crops exclusively for subsistence farming. In both developed and developing countries, smallholder farmers are prone to accept technologies that are well aligned to their needs. The effect of the technology depends on how it is interpreted and filtered by pre-existing attitudes and cultural beliefs. This explains why perception and acceptance of CRISPR, especially in agri-dependent communities, is strongly culturally dependent and therefore differs from country to country. Patent systems raise fundamental issues of accessibility such as the consolidation of leading market players, as wealthy agrochemical companies could have fundamental influence on agricultural production.

General Public

Most people are scared of what they do not know. Many concerns that arise regarding CRISPR implementation are often related to those that occurred in the past with GMOs. Reluctance to accept this technology may, for some people, be grounded in the fact that CRISPR involves DNA editing, which raises fundamental ethical, social, and environmental concerns. For others skepticism surrounding CRISPR lies in its unforeseen risks, and therefore, its safety. Additionally, people are concerned about the quality, taste, and price of their food. Therefore, the dissemination and transparency of knowledge could play a large role in affecting consumer attitudes.

SCENARIO-BASED TAKEAWAYS & POINTS OF ACTION (see Annex 5)

1. Key Takeaway: A focus on minor, staple, and native Indigenous crops only enhances equality if this is something that relevant communities desire. Assumptions cannot be made by external third parties as to what is beneficial for farming communities or smallholder farmers. When considering food security it is essential to reflect on food sovereignty and what constitutes autonomy. In an effort to minimize inequalities sovereignty must be reflected through the decision-making process, meaning that smallholders, farming communities and all affected parties must have decision making rights surrounding CRISPR technology and its implementation, and not be forced to accept actions deemed helpful by external parties.

Point of Action: It is vital to co-create participatory spaces that not only give farmers a voice but also consider the pre-conditions of said voice through awareness raising and the capacity to mobilize. These spaces must be designed not only for, but also by smallholders in collaboration with scientists and ethicists to ensure that information is translated clearly with the intention of minimizing bias. The United Nations should establish a neutral third-party body to co-create these objective spaces where farmers and scientists can share knowledge.

2. Key Takeaway: Plant breeders’ rights do not necessarily ensure increased biodiversity. Although perhaps a better alternative than patents, plant breeders’ rights could still lead to the privatization of microorganisms, genes, cells, plants, and seeds, which could heavily restrict farmer access to traditional varieties, in extreme cases leading to accusations of biopiracy and the confiscation of seeds.

Point of Action: Regulation plays a large role in the impacts of plant breeders’ rights. For example, under the 1991 Act of the UPOV Convention, subsistence farmers are exempt from abiding by breeders’ rights since their practice is not done for commercial purposes. However, there is no clear definition as to what defines a subsistence farmer: what amount of sales or income defines them as subsistence or not? If even one sale could disclude them from being defined as subsistence the benefits of such laws are limited.
3. Key Takeaway: Open source and easier access to CRISPR technology can only be seen as promoting equality if such access provides equal opportunity for all parties. Certain actors may not be interested in implementing CRISPR technology in their agricultural systems, meaning that open access provides limited benefits to those users. It may even harm their interests if increased circulation of CRISPR seeds and crops enhances cross-pollination between CRISPR and non-CRISPR plants. Not only would this limit their freedom of choice but could ultimately lead to intellectual property rights issues for smallholders, which could further exacerbate inequalities.

Point of Action: The extent that these technologies are taken up by farmers can have impacts on non-adopters. This means that it is essential to protect the interests of non-adopters through legal measures. Cross-pollination occurs naturally, meaning that farmers already have the methods in place to minimize risk. Yet, if unintentional cross-pollination does occur with a CRISPR-edited crop, farmers must not be forced to pay if the CRISPR seed is patented, nor forced to destroy their crop, as has occurred in the past with patented GM seeds.

RECOMMENDATIONS:

- Safety research should be performed exclusively by unaffiliated parties who are funded by the public sector.
  - Public-private partnerships must be excluded from this process to help ensure neutrality.
  - Public outreach and engagement are essential to help create a knowledgeable public.

- If implemented, CRISPR-edited crops should be edited to enhance climate adaptivity (drought, heat-stress, etc.) and resistance to insect-pests, not edited to increase herbicide resistance. Additionally, CRISPR research should focus on minor and staple crops that provide nutritional value and contribute to food security and food sovereignty.
  - This will help to ensure that biotechnology does not further encourage monocropping.
  - These varieties should be actively promoted to support sustainable agricultural practices and nutritional security.

- Creation and implementation of regulation schemes for different levels of gene-editing.
  - Regulation should be designed for all levels of gene-edited crops, and potentially be differentiated by technology.
  - For example, intra-species vs. transgenic editing should have different dictate and labelling.

- Clearly delineated international labelling regulations that ensure national compliance and market transparency.
  - All nations must comply with international standards as well as standards of specific countries that have stricter regulations than the international standard if choosing to export to said nation.
  - Labelling must also ensure consumers’ freedom of choice.

- Informed choices guided by the Responsible Innovation Framework: o Provides a foundation for inclusion and transparency of CRISPR technology through anticipation, inclusion, reflexivity and responsiveness.
  - Uses principles of collective stewardship and democratic governance of science and innovation in CRISPR implementation.

FINAL CONSIDERATIONS & LOOKING TOWARDS THE FUTURE

In an effort to mitigate food insecurity and enhance climate-smart agriculture it is essential that all involved parties approach the topic with humility. GMOs should not be taken as a model for CRISPR implementation, nor as an indicator for the inevitable outcomes of CRISPR, rather, they should be viewed as a cautionary tale for how lack of transparency and governance can muddy technological implementation. CRISPR technology should be implemented following principles of care, such as the precautionary principle. Additionally, technological aims should be clearly delineated and agreed upon in tandem with regulation, labelling and education. Education, or at the very least transparency, should be paramount when considering the testing and implementation of gene-editing technologies to ensure that all needs, such as environmental safety and ethics, are met. In addition, proper distribution mechanisms for the democratization of technology must be implemented to enhance accessibility and inclusion of structure and post-structural inclusion. This includes the establishment of neutral third-party bodies to co-create objective spaces where farmers and scientists can share knowledge.

CRISPR is not a panacea to the threats of climate change nor food insecurity, but rather it is a tool in the toolbox and now is the time to figure out its usefulness. Depending on the context, CRISPR technology can be framed for profit or for life. This does not mean that the two are completely antithetical to one another, but rather that there are different aspirations depending on the user and it is essential to understand that life should take precedence. Additionally, it must be made clear that risks and ethics cannot be separated.

Paradoxically there is a simultaneous lack of trust and blind faith in technology. This contradiction stems from a general lack of transparency and education surrounding technology, and the desire for technologies to be cure-all solutions, which creates reductionist mentalities when holistic systems are necessary to mitigate food insecurity. Social scientists and civil society must be integrated in technological discussions from the beginning, creating space to openly discuss concerns around gene-editing technology and create proper regulation. This can also help inform end-users, meaning both farmers and consumers, so that they can make informed choices based on knowledge and not fear.


32. PS Bindranan1, AC Franke1, DO Ferraro2, CM Ghersa2, LAP Lotz1, A Nepomuceno3, CCM van de Wiel1, M. S. (2010). GMO-RELATED SUSTAINABILITY: A STUDY ON IMPACTS, RISKS AND OPPORTUNITIES OF SOYBEAN PRODUCTION IN LATIN AMERICA.


### ANNEX I. CONSULTED EXPERTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Position</th>
<th>Interview Date</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonham, Vence</td>
<td>National Human Genome Research Institute</td>
<td>Senior Advisor of NHGRI</td>
<td>18/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Coatti, Mauro</td>
<td>Syngenta</td>
<td>Head Technical Support</td>
<td>3/12/2019</td>
<td>Italy</td>
</tr>
<tr>
<td>de Wiel, Clemens van</td>
<td>Wageningen University</td>
<td>Scientist genetic diversity</td>
<td>28/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>der Oost, John van</td>
<td>Wageningen University</td>
<td>Personal Chair</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Glenna, Lelan Luther</td>
<td>Pennsylvania State University</td>
<td>Professor</td>
<td>26/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Jenkins, Dan</td>
<td>Pairwise</td>
<td>Regulatory Strategy Lead</td>
<td>22/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Koepsell, David</td>
<td>Universidad Autónoma Metropolitana, Xochilmilco</td>
<td>Author, Philosopher, Professor, Attorney</td>
<td>19/11/2019</td>
<td>United States of America/Mexico</td>
</tr>
<tr>
<td>Kyrou, Kryros</td>
<td>Imperial College</td>
<td>Researcher</td>
<td>28/11/2019</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Lotz, Bert</td>
<td>Wageningen University</td>
<td>Researcher</td>
<td>22/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Macnaghten, Philip</td>
<td>Wageningen University</td>
<td>Personal Chair</td>
<td>28/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Mampuys, Ruth</td>
<td>COGEM</td>
<td>Scientific Secretary</td>
<td>29/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Montenegro, Maywa</td>
<td>University of California, Davis</td>
<td>Postdoctoral Research Fellow</td>
<td>5/12/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Mugwanya, Nassib</td>
<td>NC State University</td>
<td>Phd Student</td>
<td>25/11/2019</td>
<td>Uganda</td>
</tr>
<tr>
<td>Perls, Dana</td>
<td>Friends of the Earth</td>
<td>Senior food and agriculture campaigner</td>
<td>27/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Quaye, Wilhelmina</td>
<td>CSIR-Science and Technology Policy Research Institute</td>
<td>Head of Division</td>
<td>2/12/2019</td>
<td>Ghana</td>
</tr>
<tr>
<td>Schaat, Jan</td>
<td>Wageningen University</td>
<td>DLO Researcher</td>
<td>22/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Smeeckens, Sjef</td>
<td>Institute of Environmental Biology, Utrecht University</td>
<td>Vice Dean, Faculty of Science</td>
<td>20/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Smulders, Rene</td>
<td>Wageningen University</td>
<td>Business Unit manager Plant Breeding</td>
<td>26/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Sommer, Martin</td>
<td>IFOAM</td>
<td>Policy Coordinator on GMOs, Patent and Seeds</td>
<td>29/11/2019</td>
<td>Germany</td>
</tr>
<tr>
<td>Specter, Micheal</td>
<td>The New Yorker</td>
<td>Staff Writer</td>
<td>25/11/2019</td>
<td>United States of America</td>
</tr>
</tbody>
</table>
ANNEX II. GLOSSARY

- **Abiotic stress**: defined as the negative impact of non-living factors on living organisms of a specific environment.
- **Amylose**: a component of starch characterized by its straight chains of glucose unit.
- **Biofortification**: the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding, or modern biotechnology.
- **Biotic stress**: defined as a stress that is caused in plants due to damage instigated by other living organisms like fungi, parasites, weeds, insects of cultivated plants.
- **Breeding**: the process of producing plants or animals by sexual reproduction - The process of bearing offspring; reproduction.
- **Cross pollination**: the process by which pollen is carried from one flower to another by wind, insects, etc.
- **Eutrophication**: the process by which a body of water becomes enriched in dissolved nutrients that stimulates the growth of aquatic plant life usually resulting in the depletion of dissolved oxygen.
- **Gene flows**: the passage and establishment of genes typical of one breeding population into the gene pool of another.
- **Genome**: the genetic material of an organism.
- **Landraces**: traditional varieties of a species which have distinct identities.
- **Malnutrition**: faulty nutrition due to inadequate or unbalanced intake of nutrients or their impaired assimilation or utilization.
- **Mutagenesis**: a laboratory technique where DNA mutation is deliberately engineered to produce mutant genes, proteins, strains of bacteria or other genetically modified organisms.
- **Nitrogen fixation**: the conversion of atmospheric nitrogen into a combined form through chemical and especially biological action.
- **Subsistence farming**: farming or a system of farming that provides all or almost all the goods required by the farm family usually without any significant surplus for sale.
- **Transgenic**: being or used to produce an organism or cell of one species into which one or more genes of another species have been incorporated.
ANNEX III. METHODOLOGY

INTERVIEW ANALYSIS
For this policy brief, 23 experts from different fields and sectors were consulted through structured interviews. Interviews were then transcribed and collected data analyzed through the inductive thematic analysis. Besides providing knowledge, some experts were also consulted for feedback on the policy brief. A full list of interviewed experts can be found in the table below.

STAKEHOLDER ANALYSIS
The future development of CRISPR technology in the agricultural sector will potentially impact a large number of actors. The following stakeholders have been recognized: technical scientists and researchers, social scientists, NGOs, the public and small agrri-dependent communities. The data collected through interviews and literature helped identify their current perspectives, concerns, expectations and needs. Analyzing their opinions shaped predictions for the anticipated effects CRISPR might have on them.

SCENARIO ANALYSIS
Conversations with experts revealed that the future of CRISPR technology will be highly determined by a set of different driving forces. The data collected through interviews helped identify the following drivers: regulation, transparency, safety, public perception and knowledge. As a result, the future impacts of CRISPR in the agricultural sector are highly uncertain. Therefore, this policy brief uses explorative scenarios to analyze how the aforementioned drivers might influence the future development of CRISPR and its associated benefits and risks. The scenarios used in this policy brief are exclusively exploratory.
Rice provides more than 50% of the daily calories for half the world’s population and it is the most important staple crop for the developing world. As climate change becomes more evident, it will likely have negative impacts on global rice production. Due to its great economic and social importance and high vulnerability to environmental hazards, there is a need to improve its agronomic characteristics. Currently, the creation of hybrid seeds does not guarantee that all future generations will have the same highly-efficient seeds. Scientists from University of California, Davis have implemented CRISPR technology to create drought tolerant, high-yielding hybrid clonal rice seeds. Specifically, the experiment demonstrated that CRISPR is able to alter existing sexually produced rice to asexually produced rice. CRISPR-edited clone rice seeds will reproduce on their own, meaning that each generation will carry on the same highly-efficient seeds.

**Potential benefits**
- Clone seeds could assure highly-efficient seeds for each generation, contributing to food security
- Smallholder farmers could replant seeds from their own crops, cutting down seed expenditure (if CRISPR-edited rice will be free from patents)

**Potential risks**
- Research still needs to be done in order to assure all generations will be equally productive
- A single virus could threaten fully homogenous varieties, potentially eradicating the entire crop
- If the price of CRISPR-edited rice is higher than conventional rice, it won’t be accessible to low income populations, thus exacerbating inequalities
# ANNEX V: CRISPR-DEPENDENT INEQUALITIES

<table>
<thead>
<tr>
<th>Social</th>
<th>Future Scenario A: Increased Inequalities</th>
<th>Future Scenario B: Decreased Inequalities</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Little to no focus on minor crops</td>
<td>• Potential loss of traditional crops and genetic diversity</td>
<td>• Focus on minor and staple crops that provide nutritional value</td>
</tr>
<tr>
<td>• Knowledge gap between scientists, users, and consumers</td>
<td>• Exclusion smallholder farmers</td>
<td>• Independence of smallholders due to open access to improved varieties and affordable sourcing</td>
</tr>
<tr>
<td>• Public perception influenced by past GMO debates</td>
<td>• Greater benefits to big land holders who are better connected to powerful entities</td>
<td>• High level of lay people involvement helps increase public understanding</td>
</tr>
<tr>
<td>• Global food insecurity</td>
<td>• Major players set uniform technical standards, making the system efficient but exclusive</td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Biodiversity risks</td>
<td>• Undermine food security and sovereignty</td>
<td>• Increase food security</td>
</tr>
<tr>
<td>• Food production affected by climate change</td>
<td>• Genetic diversity loss</td>
<td>• Enhanced agrobiodiversity</td>
</tr>
<tr>
<td>• Climate resilient communities</td>
<td></td>
<td>• Mitigation of climate risks</td>
</tr>
<tr>
<td>• Limited land and water availability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Deforestation and land degradation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Technology concentrated in developed countries (patents)</td>
<td>• Plant breeders’ rights</td>
<td>• Plant breeders’ rights</td>
</tr>
<tr>
<td>• Knowledge, skills and research concentrated in developed countries</td>
<td>• Technology patents for CRISPR held by a few patent holders that license on conditions that can only be met by big agribusiness</td>
<td>• Equal sequencing of all crop genomes</td>
</tr>
<tr>
<td>• Technological Investments from developed countries</td>
<td>• Developed countries export their knowledge/skills to the Global South</td>
<td>• CRISPR/Cas9 license can easily be obtained under non-restrictive conditions</td>
</tr>
<tr>
<td>• Mapping genomes of major crops only</td>
<td>• Sequencing the genome of major crops only</td>
<td>• Development of the flanking technologies, including methods to transform and regenerate minor and staple crops that provide nutritional value</td>
</tr>
<tr>
<td>Regulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Fragmented regulation favor monopolies</td>
<td>• Pro-patent and proprietary regulations</td>
<td>• Easier access to the technology through inclusive regulations</td>
</tr>
<tr>
<td>• Limited accessibility due to patents</td>
<td>• Top-down international agreements</td>
<td>• Region-specific</td>
</tr>
<tr>
<td>• Lack of international governance or global consensus</td>
<td>• Regulation is not region specific-implementation issues at the ground level</td>
<td>• Bottom-up international agreements</td>
</tr>
<tr>
<td>• Government is not able to keep pace with high-speed innovation of the technology, often resulting in outdated and insufficient regulation</td>
<td>• Government is not able to keep pace with high-speed innovation resulting in outdated and insufficient regulation</td>
<td>• Regulation keeps pace with innovation</td>
</tr>
</tbody>
</table>

---

**Environment**: Biodiversity risks, Food production affected by climate change, Climate resilient communities, Limited land and water availability, Deforestation and land degradation.

**Technical**: Technology concentrated in developed countries (patents), Knowledge, skills and research concentrated in developed countries, Technological Investments from developed countries, Mapping genomes of major crops only.

**Regulation**: Fragmented regulation favor monopolies, Limited accessibility due to patents, Lack of international governance or global consensus, Government is not able to keep pace with high-speed innovation of the technology, often resulting in outdated and insufficient regulation.
Human Germline Gene Editing

A Reassessment of the Parameters to a Moratorium

North vs. South
- Implications of GGE on medical care in the Global South

Value of Life
- Implications of discrimination against the disabled

Consent
- Moral obligation vs. reproductive rights

Participatory Process
- Who and who is not at the table and why
INTRODUCTION

When CRISPR/Cas-9 was first used to edit nonviable human embryos in 2015, the debate on whether gene editing should be used to make heritable changes in human beings intensified. In three short years, Dr. He Jianku would announce the birth of the world’s first germline edited children. Dr. He’s announcement sparked outrage across the globe, with his research crossing a line thought to be set in the world of gene editing. Though He’s work had ethical issues in terms of informed consent and best practices, the prospect of germline editing children brought the debate on heritable gene editing regulation to the forefront of the scientific community. Though most experts support a moratorium, with the majority believing a ban is best practice, others believe a temporary pause will give time to evaluate regulation in order to move forward with GGE.

Determining the best form of regulation for GGE will be challenging. But the conversation is one that needs to be happening at a larger scale, beyond the realm of scientists and policy specialists. It requires the inclusion of a diverse coalition of geographies, demographics, and lived experiences to help frame the future of human germline gene editing.

GERMLINE GENE EDITING IN CLINICAL TRIALS

Herein, germline gene editing refers to the editing of heritable genes in viable human embryos with the intention of reproduction. The brief will specify when speaking on the use of germline gene editing in research settings or somatic gene editing where edits are performed to non-reproductive cells for the intention of treating diseases in humans, rather than embryos.

CURRENT DEBATE

The debates about GGE are widely varied - as diverse and expansive as the human mind can fathom. Some scientists find these discussions counterproductive, believing the acts of one individual should not be a deterrent to the potential benefits GGE could provide. Yet others wonder why GGE is even a conversation when there are other alternatives available for reproductive assistance that are proven to be safer and surer. Heritable genome editing begs many moral quandaries that have scientists questioning next steps.

Those who push for a moratorium are looking for time to evaluate the consequences of such research before making regulatory decisions. Others feel the moratorium discussion is distracting as it serves only as a temporary solution without forcing the need for future planning. Yet others are concerned about broader societal views - the why of pursuing heritable genome editing in the first place. Central to the discussion is the realistic need for human germline gene editing clinical trials. Current reproductive assistance technologies address many of the concerns GGE would attempt to fix. At present, the short- and long-term effects of genetically altered heritable traits is unclear. The lack of scientific knowledge on GGE challenges the ethics of promoting research. On the one hand, there is risk associated with informed consent on behalf of parents as well as the genetically modified offspring. While the moral concerns on informed consent have taken center stage in the media portrayal of GGE, there exist other prominent ethical challenges needing to be addressed, such as inequality for women and disabled bodies as well as other reproductive challenges and concerns of eugenics. This by no means diminishes the need to consider informed consent an important part of the discussion, but rather this brief intends to draw attention to other considerations that will help inform regulation.

Central to the discussion is the need for human germline gene editing clinical trials. At present, there exist alternative forms of gene editing and therapy that can address many of the concerns GGE would attempt to fix. The use of GGE in clinical trials is intended to produce heritable traits that can be passed down to offspring. At present, the short- and long-term effects of genetically altered heritable traits is unclear. The lack of scientific knowledge on GGE challenges the ethics of promoting research. On the one hand, there is risk associated with informed consent on behalf of parents as well as the genetically modified offspring. While the moral concerns on informed consent have taken center stage in the discussion about GGE, there exist other prominent ethical challenges needing to be addressed. This by no means diminishes the need to consider informed consent an important part of the discussion, but rather this brief intends to draw attention to other considerations that will help inform regulation.

KEY MESSAGES

- Human germline gene editing, in its early stages, is not currently safe enough for clinical trials
- Moving forward with GGE technology needs to consider ramifications on minority groups, as they will be impacted the most (specifically women, disabled bodies, and the global south)
- Many experts have called for a moratorium, though regulation beyond this is fraught with debate
- Discussion needs to be had with a larger community to determine if and how technology will move forward.
Challenges

It is important to note that there exist many technical issues to the use of germline gene editing that would need to be solved with further lab research before the implementation of future clinical trials. GGE requires the use of preimplantation genetic diagnosis (PGD) and in-vitro fertilization (IVF), adding to current complications both of these technologies present as well as the unknown consequences of GGE. While the discussion on what GGE could provide to society is expansive, the consequences of implementations are equally fraught with debate. Currently, heritable GGE is known to have many risks associated with its use. There is a high risk of harming future generations by eliminating some forms of genetic diversity needed to sustain communities. In some cases, reducing the risk of one disease has been found to increase the risk of others, as is true for edits to type-1 diabetes impacting the likelihood of contracting Crohn’s disease. The baseline consensus from experts, both pro- and anti-GGE, is an immediate halt in research, at least until the technology is deemed safe.

INEQUALITY

Heritable germline gene editing raises a difficult and near impossible question: does society value some lives over others? What factors determine how these lives are valued? GGE has the potential to add to a slew of global social justice issues by challenging the rights of underrepresented groups. Without proper regulation, GGE could put minority populations at risk. Though experts have expressed challenges to various minority groups in op-eds and commentaries, very little academic literature covers the need for including more diversity in the discussion around heritable germline editing. Here, we have outlined the debate for three underrepresented communities, but this is by no means an exhaustive list or complete discussion.

Women

The academic literature has yet to emphasize the necessary role biologically female individuals will play in the development of heritable germline gene editing. Simonstein (2015) has theorized that the inevitable role women would need to play is obvious and therefore overlooked. Research in germline gene editing requires massive numbers of human eggs, and the long-term health effects of egg harvesting procedures are not known. Further, women will bear any health risks of gestating pregnancies started with gene-edited embryos. Current forms of assisted reproductive technologies already put women at higher risk for obstetric complications as well as other abnormalities affecting maternal health. Because GGE requires the use of both PGD and IVF, implementation of GGE would run the same risks as both assistive reproduction technologies, as well as add the yet unknown risks of GGE and carrying to term a genetically modified child. Women partaking in GGE studies may also run unforeseen risks in relation to fetal DNA. Fetal DNA has been found in maternal blood for months following birth and, although edits would occur prior to insertion, the risk of this edited DNA entering the maternal bloodstream is likely and the consequences are unknown.

If given the green light, research must first focus on safeguard development, with special attention paid to the potential risks experienced by female patients and egg donors. The process of obtaining consent of participants must also be carefully designed. Societal pressures on women to have healthy children already have mental and emotional impacts on reproductive efforts, with PDG+IVF+GGE introducing further complications by encouraging the systemic belief that parents should risk everything to give their child the best start to life, adversely affecting their ability to make a decision free from coercion or influence. Moreover, it is important to engage women in the discussion around whether this technology should be developed and how it should be implemented. When it comes to reproduction, women's bodily autonomy is already rife with debate. Allowing PDG+IVF+GGE to be an option to address reproductive challenges will likely exacerbate the anti-feminist rhetoric that often accompanies these discussions.

Disabled communities

The UN’s Universal Declaration of Human Rights, article 1, says that all people are born free and equal. But by allowing the progression of human germline gene editing trials, regulatory agencies permit the continued discrimination of disabled bodies. The unregulated use of GGE would provide parents the opportunity to terminate pregnancies based on these discriminations, sending a clear message to those in the disabled community about society’s view and value of their lives. Rather than address systemic issues, GGE proposes a technological "solution" in place of necessary societal change. This form of ableism, already pervasive in society, furthers the rhetoric that the disabled community has little to offer society and that because their disabilities (viewed often as problems) can be “fixed” with technology, disability rights and advocates are less valued. An additional complex conversation concerns who decides what conditions GGE would target, especially when such discrimination blurs the line between disability and disease. While society perpetuates the belief that disability is a horrible, life-altering mutation, the disabled community fosters a rich culture to be proud of.

North/South divide

Current gene therapy and editing research utilize available DNA pools, with most pools coming from the global north. These DNA pools exclude some of the world’s largest populations, leaving the realistic impacts of such technologies up for debate and the most in need populations at risk. Inconsistent global regulation of GGE could also lead to medical tourism. Different countries have varied laws regulating existing assistive reproduction
practices and often receive medical tourists who can afford to bear the costs of travel and procedure.  
There is also an indirect link that can be traced to resource allocation and opportunity cost. Given the limited amount of money available to research, the customization of GGE would likely skyrocket prices. As previously stated, GGE requires both PDG and IVF, requiring both investment and infrastructure to support such a procedure. Somatic gene therapies can cost customers upwards of US$1.8 million per treatment. These raise concerns over the ethical implication of shifting money into heritable gene editing research when people are suffering from lack of other basic human needs.

SUSTAINABILITY  
Disease & Reproduction  
At present, in vitro GGE research has been considered for the purpose of learning more about human development and to understand infertility issues. But one potential for heritable germline editing clinical trials is the elimination of disease strains. Proponents of GGE have suggested the technology could delete rare diseases strains that currently cause immense struggle to patients. One application would be the ability to eliminate the chance of genetically transmitted diseases, especially single-allele recessive diseases (image 1) (i.e. Huntington’s or Cystic fibrosis). Though it would not be considered a medical necessity, some family planners may seek to have biologically related children. PDG is the current pre-screening technology used to analyze the presence of in-vitro embryos. Parents then select against unhealthy eggs for reproduction. Though GGE could, in extremely rare cases when no healthy embryos are produced, eliminate disease strains, PDG would still be necessary to determine if the embryos are carrying the mutated genes.

Another unique opportunity if the ability to replace the genome with a protective genome that can guard against future generations succumbing to diseases such as cancer, diabetes and heart disease. Some possibilities of this technology include making immune cells resistant to cancer cells and preventing the reproduction of the HIV virus. However, the risk of GGE use in either scenario is still unknown, with many questions about how or when changes to DNA will develop and their impact on health and safety. The prospects of GGE in clinical trials does not currently believed to alleviate many of the concerns associated with existing technologies used for the selection of healthy embryos for reproduction.

Figure 1: In/around disease and reproduction sections  
Superhuman Race  
Human germline editing poses a worrisome vision for the future - one where the human population is being cultivated by eugenics into two divergent species: superhuman edited and unedited races. This could also come in the forms of biological weapons, increasing military abilities of strength, resistance to injury, pain alleviation, or intelligence. Furthermore, the existence of heritable GGE technologies could create obsolescence of certain children, with those not receiving the most update edits being discriminated against. It will further feed into the idea that inherent biological advantages exist, causing tension, prejudice, and violence, as seen in cases of eugenics across the globe.

REGULATION  
Several leading organizations in the field have released statements or recommendations regarding the future political landscape of germline editing (image 2). The 2017 US-based National Academy of Sciences released a report condoning some forms of human germline editing, despite the prevailing international position reflected in the binding Council of Europe Convention on Human Rights and Biomedicine, which prohibits the use of GGE to intentionally produce heritable modifications and the UNESCO declaration that claims GGE is against human dignity. Some countries have taken initiative to produce policy on GGE research with bans in place in Canada, Australia, and much of Europe as well as a ban in the US prohibiting the FDA from reviewing applications involving genetically modified human embryos.

Regulation, however, will not entirely halt rogue scientists. At present, some researchers offer unregulated genetic therapy options, with heritable GGG likely to follow in this path. The need for international cooperation in regulation is paramount to the safety of patients.
Legal parameters need to be considered carefully, as the room for loopholes around an ever-evolving technology could pose problems. The arguments to allow GGE need to be evaluated critically, in an effort to ensure the technology is being employed for the right reasons rather than clients and scientists finding ways around legal means by over-emphasizing the benefits. Some researchers believe that the approach towards a complete ban of heritable genome editing is detrimental to the cause of innovation in science. Alternatively, a moratorium has been suggested that many experts support but has no international government backing to become binding.

Regardless of perspectives on a ban, there is consensus among experts to only move forward with the technology when it is considered safe, but “safe” is dependent on various factors and likely will change depending on the scenario. In an economy that is driven by consumer demand, where will the reign for managing this technology rest? With monopolistic corporations dominating the tech market, this can lead to genetic editing being run based on profit generating motives. Who is controlling the narrative on human gene editing until then remains one of the most vital discussions to the future of GGE. The inclusion of civil society, racial and social justice scholars, law and policy experts, in addition to the scientific community and bioethicists is key, so that all aspects of social equality can be considered before moving forward with policy.

RECOMMENDATIONS
The current call for a moratorium has yet to be backed by any international governing bodies but this support is needed in order to ensure the safety of potential participants. But a moratorium will only be a temporary fix and will require great debate and capacity building to ensure proper regulation is developed.

The emphasis placed on stakeholder engagement in several commentary pieces on heritable GGE should not be taken lightly. The largest stakeholder groups in the world of heritable genome editing have yet to have space at the decision-making table. Despite some recognition of the concerns for women, disabled communities, and the global south, each stakeholder group has been physically underrepresented in the ongoing debates. International organizations and governing bodies need to work to not only include these expert voices, but to educate minority groups in the public sphere on the risks of GGE implementation for reproduction. While including public and patient perception is a step in the right direction, having a voice is not enough. A truly successful participatory process requires individuals to have access, standing, and influence.

Part of this decision-making process must include development of safeguards for affected groups. Parameters must be set for if, when, and how GGE can be used with particular attention paid to the societal structures that conflate disability and disease and govern women’s bodies. To reduce inequalities in technology gain, there need to be investments to global south DNA pools to help further current gene therapy research for different ethnic and racial groups. The technology should also remain un-privatized to avoid patenting and cost changes in a commercialized market.

Effective regulation at the global scale will require international cooperation and a plan for enforcing legal repercussions for those going against regulation. This will help to halt the expansion of medical tourism and ensure the safety of all citizens of the globe. There are challenging moral, ethical, and social issues surrounding the field of heritable GGE.

CONCLUSION
Scientists, ethicists, policymakers, civil society, and others have expressed concerns on the future of heritable genome editing. While the number of nations putting at least partial bans on heritable GGE trials is growing, global consensus is still lacking, leaving space for unethical and immoral action. Moreover, the information easily accessible to the public often comes from media and news outlets, where the portrayal of GGE tends to push extreme viewpoints, with expression of a complete dystopian view or over-promotion and hype about its benefits. At other times, corporate media has also published sensational headlines showing that the reports of organizations working on policy around GGE have given the green light for designer babies, highlighting only certain aspects of the publication and not a holistic picture. The future of heritable genome editing presents many challenges, but most important to the discussion is an evaluation of what is means to be human.


## ANNEX I. CONSULTED EXPERTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Position</th>
<th>Interview Date</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Athanasiou, Tom</td>
<td>Eco Equity</td>
<td>Director</td>
<td>14/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Baylis, Fraçoise</td>
<td>Dalhousie University, Impact Ethics</td>
<td>University Research Professor</td>
<td>27/11/2019</td>
<td>Canada</td>
</tr>
<tr>
<td>Darnovsky, Marcy</td>
<td>Center for Genetics and Society</td>
<td>Executive Director</td>
<td>18/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Ghosh, Shubha</td>
<td>Syracuse University</td>
<td>Professor of Law, Director</td>
<td>14/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Syracuse Intellectual Property Law Institute</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hasson, Katie</td>
<td>Center for Genetics and Society</td>
<td>Program Director</td>
<td>18/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Iqbal, Minah</td>
<td>Broad Institute</td>
<td>Project Manager</td>
<td>14/09/2019</td>
<td>United States/Pakistan</td>
</tr>
<tr>
<td>Koepsell, D.R.</td>
<td>Comisión Nacional de Bioética</td>
<td>Author, Educator, and Entrepreneur</td>
<td>19/11/2019</td>
<td>Mexico</td>
</tr>
<tr>
<td>Kofler, Natalie</td>
<td>Morse College at Yale</td>
<td>Molecular Biologist and Bioethicist</td>
<td>3/12/2019</td>
<td>United States of America</td>
</tr>
</tbody>
</table>
ANNEX II. METHODOLOGY

EXPERT INTERVIEWS
Experts from diverse backgrounds and fields of study were consulted through semi-structured interviews. Snowball sampling was also used to reach out to experts in the field of bioethics, germline research, disability advocacy, indigenous peoples, people of color, and legal experts. Interviews were recorded for transcription purposes and analyzed using thematic analysis.

RISK ANALYSIS & MANAGEMENT
Risk scenarios were selected based on thematic frequency in media, scientific literature, and expert interviews. Changes in inequality were supported by literature review and expert validation. Risk management strategies were suggested based on literature review and expert interviews.
## ANNEX III. RISK ANALYSIS

<table>
<thead>
<tr>
<th>Issue</th>
<th>Current Status</th>
<th>FUTURE STATUS: Increased Inequalities</th>
<th>FUTURE STATUS: Decreased Inequalities</th>
<th>Risk Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Informed Consent of future generations</strong></td>
<td>Societal views/pressure have potential to impact decision-making (coercion, influence)</td>
<td>Power dynamics of intergenerational control; decision of older generation to determine genetic outcomes of future generations</td>
<td>N/A</td>
<td>Reevaluation of societal need for gene editing technologies; various perspectives and knowledge sharing for informed decision-making by parents</td>
</tr>
<tr>
<td><strong>Prevent transmission of genetically heritable conditions</strong></td>
<td>Other pre-screening technologies to use Not enough research to determine practical use of technology</td>
<td>Risk of altering genes that have negative impact on other strains of genetic or acquired diseases Risk of introducing harm to the future child through off-target edits, mosaicism, epigenetic effects, and the unpredictable effects of altering embryonic DNA</td>
<td>Potential to become safe alternative to eliminate risk</td>
<td>Proper laboratory research on disease strains and germline editing before clinical trials</td>
</tr>
<tr>
<td><strong>Quality of life</strong></td>
<td>Challenges to current pre-screening technology regarding fatal diseases</td>
<td>Perpetuation of negative view and discrimination against disabled community</td>
<td>Limit challenges and suffering of future generations Moral obligation to use technology if the risks of not outweigh consequences of inaction</td>
<td>Disability v. disease caveat - strict parameters for GGE use in fatal mutations only</td>
</tr>
<tr>
<td><strong>Eugenics</strong></td>
<td>Historical of eugenics in different forms in various parts of world (against people of color, different ethnicities, and disable community)</td>
<td>Disparity between genetically modified individuals versus the ‘naturals’ without enhanced capabilities Reinforces genetically determinist beliefs that some are biologically or genetically “superior” to others</td>
<td>N/A</td>
<td>Complete ban on germline gene editing for non-fatal disease mutations</td>
</tr>
<tr>
<td><strong>Accessibility</strong></td>
<td>Basic healthcare already inaccessible to many regions of the world</td>
<td>Capitalist tendency likely to favor rich (within countries or through medical tourism) GGE likely to follow suite of current inaccessibility to healthcare in certain regions</td>
<td>Non-privatization of technology would make it more accessible</td>
<td>Regulation limiting scope of GGE for certain cases and specific areas</td>
</tr>
</tbody>
</table>
INTERNATIONAL PERSPECTIVE

stance on germline gene editing by leading international organizations

MORATORIUM/TEMPORARY BAN SUPPORTED
UNESCO International Bioethics Committee
International Summit on Human Genome Editing
Council of Europe Committee on Bioethics

PROCEED WITH CAUTION
Association of Genetic Nurses and Counselors
Canadian Association of Genetic Counselors
International Genetic Epidemiology
National Society of Genetic Counselors
American Society for Reproductive Medicine
British Society for Genetic Medicine
Southern African Society for Human Genetics
Asia Pacific Society of Human Genetics
Human Genetics Society of Australasia
Professional Society of Genetic Counselors in Asia

APPROVAL FOR USE IS CONDITIONAL
US National Academy of Science, Engineering, and Medicine
3D Printing: A Paradigm Changing Technology

- Governments and IGOs
- Transfer of Knowledge
- Partnerships
- Research
- Investments
- Circular Economy
- Capacity Development
- Basic Needs

Wessel van Dorst, Lorena Esquivias, Sara Mancinelli, Citra Siagian
KEY MESSAGES

- Contrary to developed countries, less developed countries have started to adopt 3D printing (3DP) for manufacturing. 3DP has the potential to be positively transformative for developing countries, particularly for low-income and marginalized communities.
- The potential for developing countries lies in decentralized manufacturing, including self-manufacturing, because it provides those with no or difficult access to traditional manufacturing equipment with opportunities to create products (potentially cheaper and from local materials) to improve their quality of life. Widespread adoption is critical to offset the projected economic losses from the return of offshored manufacturing industries to developed countries, and to become less dependent on global supply chains.
- It is imperative to embed Circular and Biobased Economy principles in the early stages of adoption to avoid an alternative scenario in which more environmentally destructive localized production develops and becomes entrenched. This vision should be carried out and shared by all stakeholder involved.
- Technological breakthroughs and advancements in material sciences are consistently adding opportunities for less developed countries. Now is the time to nurture new applications and to harmonize the adoption of decentralized manufacturing with sustainability, development, and equity concerns.
- Government action is critical to nurture uptake and provide direction for human health, societal safety, and environmental protection as well as sustainability.

INTRODUCTION

Colloquially known as 3D printing (3DP), additive manufacturing is a group of technologies and processes that create physical objects through the addition of materials, usually layer upon layer (see Annex 5 for a quick overview of the basics of 3DP).¹ Currently, most products are manufactured by either subtraction (removing parts of the raw material), forming, and casting (liquefying raw materials and pouring it into molds).

3DPs initial purpose was, and in 2019 still remains, primarily prototyping. However, it is already widely—and increasingly—used for production purposes. Its advantages over the aforementioned traditional manufacturing processes include: (1) compatibility with design complexity (intricate and precise); (2) speed to market (quick prototyping and design adjusting); (3) waste reduction (both due to design possibilities and its additive rather than subtractive); (4) mass customization (only the model has to be changed); (5) low barriers to market entry (low startup costs). As such, 3DP changes how we make things, how manufacturing is organized, and who the stakeholders are in these processes.² The reduction of expansive transboundary supply chains to local production allows for decentralized manufacturing, and consequently for the inclusion of stakeholders which have no or difficult access to traditional manufacturing equipment (e.g. prosumers - production by consumers).

ADOPTION TRENDS

Currently, 3DP is largely limited to advanced industrial manufacturing or a hobby. Developed countries have a head start and are already making the leap from innovators (2.5% of the population) to early adopters (13.5%), while developing countries largely remain in the innovation stage. In 2016, private investments in 3D printers were dominated by three regions: North America (39%), Asia/Pacific (29%), and Europe (28%).³ Due to the near absence of private investments, social initiatives by governments, NGOs, and social enterprises have been critical in providing at least some level of access in developing countries. Such efforts are essential and should be increased as most of the advances in the field of 3DP are and will be driven by the commercial sector, regardless of international development endeavors.⁴

The current state of 3DP technologies and materials allows a small number of sectors to benefit in particular (e.g. aerospace, automotive, and medical and dental services).³ This is in part explained by high R&D costs that are generally earned back by high-added value applications. As a result, investments focus on innovations such as rocket engines, rather than on applications aimed at meeting basic social needs. In general, five of the seven technology groups (see Annex 5) remain highly industrial due to both the nature of the technologies and the high machine and raw material prices. Conversely, the other two groups (VAT photopolymerization and material extrusion) have seen considerable improvements and price declines due to recently expired patents. As such, they have become more accessible as prices now range from <500 USD for hobbyists, to 500 - 2500 USD for prosumers, and 2500 - 5000 USD for professionals.⁵

IS IT DISRUPTIVE?

In 2018 the 3DP industry grew from around 7 to around 10 billion USD. In comparison, industrial manufacturing is a 12.8 trillion USD industry.⁶ The expected speed and scale of its disruptive potential is subject to vigorous debate. Investment in 3DP is at an all-time high and is increasing.⁷ Tentative growth calculations suggest that if current investment rates continue, 50% of manufactured goods might be printed by 2060. Alternatively, if investment were to double every five years, this scenario may be reached as early as 2040.³
Due to simplified supply chain and manufacturing processes, 3DP manufacturing requires less labor input. This can return offshored manufacturing industries to developed countries and thus also reduce cross border trade, variously estimated on the order of 18% by 2060, or by 38% in 2040. This could reduce economic growth in developing countries because emerging economies are currently dominated by industrial manufacturing. This means that unless decentralized manufacturing is widely adopted by them, their economies may be severely impacted by 3DP. However, if developing countries are able to harness the positively transformative potential of decentralized manufacturing, new levels of economic gains may compensate for the losses and improve prospects for sustainable development and quality of life.

**POTENTIAL FOR SUSTAINABLE DEVELOPMENT**

**Economic Prosperity**

Despite the numerous advantages of 3DP, traditional manufacturing processes remain favorable in terms of: (1) mass production; (2) material choice; and (3) manufacturing of large parts. As such, 3DP is particularly suitable for low- to mid-scale production. Experts argue that 3DPs transformative impact is based on increasingly complementing and becoming integrated with traditional manufacturing, rather than replacing it. Some experts also argue that 3DP self-manufacturing can only be considered economically viable in contexts where supply chains fail or are too slow. However, others have shown that self-manufacturing can generate cost savings (e.g. <200 USD open-source research objects can replace commercial versions that start at more than 1000 USD for some purposes). See Annex 6 for the salient economic drivers for, and obstacles to, 3DP adoption.

**Social Equity**

3DP has great potential to benefit low-income and marginalized communities because it provides these groups - that typically have limited access to means of production - with ways to print products that can positively transform their lives. 3DP also has great potential for sectors such as health, infrastructure, education, and humanitarian aid. In fact, concrete economic and social value is already being created, particularly for the most vulnerable communities. Here are some examples.

**HEALTH.** Prostheses are being printed for a fraction of the cost of traditional ones. Medical experts are beginning to print organs from biomaterials.

**INFRASTRUCTURE.** Houses are being printed from biomaterials. 3DP is sometimes already a considerably cheaper option than traditional building methods, thereby particularly benefiting low-income communities. Around the world, houses for such communities are already being printed and further investment could create large opportunities to expand low-cost housing projects.

**EDUCATION.** The capacity to rapidly reproduce detailed and complex structures allows for better conceptualization of knowledge in the scientific, medical and archeological sector. The affordability of such educational enrichments and the subsequent integration of knowledge and expertise of 3DP within school curricula particularly favors students in developing countries by developing practical skills that are beneficial for employment.

**HUMANITARIAN AID.** In cases of natural disasters waiting times on critical supplies are reduced from up to twelve weeks to one or two days with 3DP. To fully develop its potential in this sector, the technology and its uses need to be adjusted to ensure operability in international aid and emergency response settings where conditions for printing are not ideal.

**OFF-GRID COMMUNITIES.** Mobile open hardware solar-powered 3DP are uniquely able to transform the living standards of off-grid communities.

**Environmental Sustainability**

Multiple environmental benefits are inherent to 3DP, mostly due to disruptive effects on the traditional supply chain. Also, it allows for radical material efficiency through innovative designs and fabrication methods. In general, less material is used because virtually all the material that is deposited will end up in the final product. 3DP allows for fast prototyping and design adjustment, and for local and on-demand production. Consequently, 3DP could transform international supply chains into local ones, reducing the need for transportation, packaging, inventory, and stock. As such, less pollution and waste is generated.

**Case Study: Building printers from local e-waste**

It is estimated that by 2020 there will be over 50 million tons of e-waste generated annually. Currently, only 17% is recycled. AB3D, a startup in Kenya, is reusing and recycling this e-waste to build 3D printers. Their main objectives are to reduce costs and to lower their impact on the environment. At the moment they still have to import filament from China. Fortunately, Precious Plastics, provides free, open source, modular, and inclusive designs (that is, using basic materials, tools, and universal parts) for shredders and extruders. When combined with integrated waste collection and management systems that ensure a steady stream of quality plastics, companies and communities can set up circular production systems. The creation and expansion of 3DP networks is essential to ensure that parties are aware of such opportunities.

**CIRCULAR AND BIOBASED ECONOMY**

It is imperative to move from linear to circular and biobased production systems. A Circular Economy (CE) “replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling, and recovering materials in production and consumption processes.” It aims to design waste out of the system, and to gradually decouple economic growth from the consumption of finite resources. Similarly, Biobased Economies (BBE) envision a shift away from dependence on fossil resources towards biomass resources. Some consider that the CE may be the application that 3DP needs to make the leap towards widespread adoption. CE
principles align with 3DP because: (1) (with the right set of chemical additives) a single polymer can be used to create a nearly infinite number of forms; (2) 3D printers can work on renewable energy; and (3) old objects can be grinded into raw materials, which can subsequently be used by printers. The technologies that are necessary to collect and process waste plastics into 3DP feedstock already exist and waste streams can provide plastic feedstock in sufficient quality and quantity. Materials degrade - at least on a micro-scale (e.g. microplastics), consequently polluting the environment. Biodegradable materials are therefore ideal because they degrade naturally under certain conditions (heat, humidity, and microbes). Materials should thus not only be biobased, but also biodegradable (bio-based does not necessarily mean biodegradable).

**BOX 1.** One company that integrates CE and BBE principles is WASP. They are currently 3D printing houses from rice production waste combined with other natural and local materials. Even though eco-sustainable housing is still in its prototyping phase, it opens a big opportunity to create affordable and environmentally-friendly houses.

There are two major obstacles to turning this vision into a reality. Firstly, the mechanical properties of plastics degrade when they are recycled (i.e. polymer chains shorten when recycled). While these polymer chains can be restored with the right set of chemical additives, it is unclear what the environmental impacts of these are. Secondly, a more persistent obstacle is the low economic appeal of recycling plastics: virgin materials are generally still cheaper. As such, regulators have a responsibility to support CE ventures through comprehensive incentive structures. Regulators could, for instance, set targets to reduce landfilling and CO2 emissions, or they could mandate the collection and reuse of resources. This would inform the public about the necessity of these efforts while simultaneously providing cheap and consistent access to material streams. The political feasibility of such efforts is enhanced by the opportunity to create local material recycling and manufacturing loops that offer concrete benefits in terms of local employment and value creation. Moreover, the biodegradable plastic polyactic acid (PLA) is the most used filament in material extrusion due to its favorable properties. The use of this material (made from plant sugars) should be advocated.

**Alternative scenario**

It is imperative to embed CE principles into new manufacturing systems before the adoption of 3DP reaches a critical inflection point in which negative or suboptimal practices become entrenched. While 3DP appears promising for sustainability, there is no guarantee that it will be. There is the possibility of an alternative scenario in which less eco-efficient localized production, higher demand for customized and nonessential consumer goods, and higher rates of product obsolescence culminate in higher resource consumption. Educating and communicating about 3DP as an enabler for circular economies from the outset can help nurture restraint in resource use.

**OBSTACLES TO WIDESPREAD ADOPTION**

*Lack of (access to) basic infrastructure.* Electricity and the internet are currently still unavailable, inaccessible, and unaffordable to a significant part of the world’s population.

*Cost.* Although the most common printers are relatively affordable, a 200-500 USD investment remains a considerable hurdle for self-manufacturing in low-income and marginalized communities. Moreover, these printers can currently only use plastics, only print small dimensions, and the quality of the printed objects may be insufficient for some purposes.

*Lack of skills and knowledge.* 3DP adoption requires (e-)literacy, computer and design skills, and a basic understanding of chemistry and material science (e.g. what kind of plastics one needs). 3D hubs indicate that at least one supervisor with this knowledge should be available at shared manufacturing spaces. To be in line with the SDGs, 3DP users also require considerable environmental knowledge and proper waste management practices and facilities.

**ENABLING DECENTRALIZED MANUFACTURING**

Reaping the positive potential of 3D for sustainable development requires that governments and other enabling actors assume the role of catalysts to enable social and economic value creation for poor, marginalized communities. They need to familiarize themselves with the technology and its possible applications, engaging in horizon scanning and producing systematic projections of potential evolutions of 3DP. This facilitates early, “upstream” identification of opportunities for social, economic and environmental gains from the technology while minimizing possible harms. Strategies need to be designed for the development of an innovation ecosystem capable of fostering most autonomous emergence, application, and scaling-up of innovations. For this, different actors, at various levels, need to be activated to promote networking and collaboration between development organizations, 3DP networks and maker communities, as well as researchers and scientists, entrepreneurs and innovators, local organizations and corporations. Maker communities with a strong desire to ‘build things that matter’ already exist and should be nurtured and supported. This can be done by ensuring such communities—and more generally less socio-economically empowered communities—have access to a free and open source library. This allows for faster and cheaper access to critical products, consequently improving their lives.
3DHUBS
One way of facilitating access is through 3D printing hubs—places with shared manufacturing services, equipment, materials, and skills. Examples of such hubs are Makerspaces, Fab labs (fabrication laboratories), and 3D Africa. Such models are able to mitigate knowledge challenges because one supervisor can guide many novices, and are environmentally friendly because the utilization per unit of machinery is high. Partnerships between NGOs, private companies, educational facilities, and governments are pivotal in such programs. They can adopt recruitment strategies and training modules to bring in and capacitate low-income communities. For instance, Fab Labs have become a combination of education, entrepreneurship, and research activities, where aspiring entrepreneurs are given free access to 3DP to set up businesses and kick-start local economies. Similarly, the non-profit 3D Africa has a special focus on empowering women. They offer training modules that are made by women for women.25
Currently, developing countries have significantly fewer hubs than developed countries, and the ones that are there are largely located in cities;4 lack of infrastructure in remote areas has inhibited programs from reaching more participants. Solving the infrastructure gap requires even more inclusive partnerships, with a high emphasis on government involvement.

RISKS
Several risks have to be addressed by different stakeholders, at various levels, to ensure that 3DP develops in line with concerns for human health, societal safety, environmental protection, and sustainability.

Safety: There are numerous health and safety hazards that have to be considered when 3D printing: (1) gases and odors released (e.g. carcinogens); (2) possible fire sources (e.g. due to highly flammable materials or due to self-replicating 3D printers which, for instance, do not have adequate quality controls); (3) hot parts; and (4) moving parts. For instance, during material extrusion when plastics burn instead of melt, it creates serious health problems.26 It is suggested that respiratory and other protective gear is used (e.g. HEPA filters or ventilation).

Environmental risks: Difficult to foresee; these include wasteful use of resources for unnecessary products, e-waste and improper disposal of liquid resins used in VAT photopolymerization. It should also be noted that recycling of plastics may backfire because it lowers the changes of plastics being banned and because it keeps plastics—and thus the potential of microplastics polluting ecosystems—in the cycle.

Danger of harmful object printing: 3DP enables printing of firearms, drugs, and biomaterials, which could pose significant threats to international security. Policymakers need to be vigilant about a whole range of products which may pose serious security risks.27

Ineffecual intellectual property (IP) rights: IPs will be challenging to uphold, as CAD models of copyrighted products are easily obtained, modified, and shared. The current body of IP law is ill-equipped to keep up with the speed and potential scale of the digitalization of consumer goods.28 Although IP rights are designed to encourage innovation and to safeguard creativity, they can also obstruct innovation. The high costs and difficulties involved in requesting a patent effectively limit their use to more experienced and wealthier innovators. Furthermore, patent (and copyright) holders may utilize their position to maximize their profits and suppress innovation (e.g. through monopolistic behavior). In both instances, IP law may stifle innovation and reward rent-seeking behavior.29 Some scholars perceive a strong relationship between IP and worsening inequalities. Succinctly put: “Inequality is not coming from technology; it is coming from our laws on the ownership of technology.”30 Proponents of this view support and advocate for open-source hard- and software. (Annex 7)

Difficulty monitoring and enforcing health and safety standards: Democratization of manufacturing may lead to the exponential growth of the amount of uncontrolled 3D printed products. Governments lose the ability to monitor health and safety standards.31 This is dangerous because printed objects may not meet safety standards (e.g. nonfood grade plastics used for food purposes). Furthermore, governments may also lose opportunities to collect (sales) taxes.28

POINTS OF ACTION
- Basic infrastructure such as electricity and internet access should be prioritized.
- 3D hubs are critical for access to 3DP. Initiatives should extend towards rural areas.
- Create legal safeguards to ensure safety for health and safety standards.
- Research efforts should be directed towards the health and environmental risks of 3D printing.
- Set up integrated waste collection and management systems to facilitate local reuse, recycling, and recovery.

LOOKING TOWARDS THE FUTURE
Technological advancements and new materials and applications are bound to overcome some of the identified obstacles and risks. Research is currently being carried out on printers that can quickly switch between materials, colors, and nozzles, consequently speeding up printing times and creating more complex products with less need for post-processing.32 Experts expect that the largest breakthroughs will come from advancements of materials that can be used, such as smart materials, ceramic materials, electronic materials, biomaterials and composites.33


## ANNEX I. CONSULTED EXPERTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Position</th>
<th>Interview Date</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alvarado Orozco, Juan Manuel</td>
<td>CONMAD</td>
<td>Head of Department</td>
<td>2/12/2019</td>
<td>Mexico</td>
</tr>
<tr>
<td>Amaefule, Chukwubuikem Felix</td>
<td>3D Africa</td>
<td>Program Manager</td>
<td>29/11/2019</td>
<td>Nigeria</td>
</tr>
<tr>
<td>Chiusoli, Alberto</td>
<td>WASP</td>
<td>Construction Engineer</td>
<td>6/12/2019</td>
<td>Italy</td>
</tr>
<tr>
<td>Bastion, Geraldine de</td>
<td>Global Innovation Gathering</td>
<td>Project Manager and Political Scientist</td>
<td>18/11/2019</td>
<td>Germany</td>
</tr>
<tr>
<td>Hernandez Valera, Elias</td>
<td>ASTRO</td>
<td>CEO</td>
<td>4/12/2019</td>
<td>Mexico</td>
</tr>
<tr>
<td>King, Joseph</td>
<td>Fab Lab Bandung</td>
<td>CEO</td>
<td>22/11/2019</td>
<td>Indonesia</td>
</tr>
<tr>
<td>Komarov, Anton</td>
<td>3Devo</td>
<td>Account Manager</td>
<td>3/12/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Lomas, Durante Javi</td>
<td>Sigrow</td>
<td>Founder</td>
<td>22/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Noort, Martijn</td>
<td>Wageningen University</td>
<td>Scientist/Project Manager</td>
<td>6/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Okwemba, Riddick</td>
<td>AB3D</td>
<td>CAD Designer</td>
<td>2/11/2019</td>
<td>Kenya</td>
</tr>
<tr>
<td>Pearce, Joshua</td>
<td>Michigan Technological University</td>
<td>Academic Engineer</td>
<td>3/12/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Peirone, Michael</td>
<td>Victoria Hand Project</td>
<td>Chief Operating Officer</td>
<td>27/11/2019</td>
<td>Canada</td>
</tr>
<tr>
<td>Wirth, Jutta</td>
<td>Wageningen University</td>
<td>Researcher</td>
<td>22/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Woodson, Thomas</td>
<td>Stony Brook University</td>
<td>Assistant Professor</td>
<td>22/11/2019</td>
<td>United States of America</td>
</tr>
</tbody>
</table>
ANNEX II. GLOSSARY

- **Bio-based Economy (BBE)**: The production of renewable biological resources and the conversion of these resources, residues, by-products and side streams into value added products.

- **Bio-based material**: Products that mainly consist of a substance (or substances) derived from living matter (biomass) and either occur naturally or are synthesized, or it may refer to products made by processes that use biomass.

- **Bio-based plastic**: Plastics in which 100% of the carbon is derived from renewable agricultural and forestry resources such as corn starch, soybean protein and cellulose.

- **Capacity Development**: Capacity development is the process through which individuals, organizations and societies obtain, strengthen and maintain the capabilities to set and achieve their own development objectives over time.

- **Computer-Aided Design (CAD)**: The use of computer software to design and document a product’s design process.

- **E-literacy**: The skill set required to make efficient use of all of the materials, tools, and resources that are available online.

- **Extended Producer Responsibility (EPR)**: A policy approach under which producers are given a significant responsibility – financial and/or physical – for the treatment or disposal of post-consumer products.

- **HEPA filter**: Filter High-efficiency particulate air filter used to trap dust or air particles.

- **Humanitarian Aid**: Delivering short-term aid immediately after a disaster to save lives under the humanitarian principles of humanity, neutrality, impartiality and independence.

- **Intellectual Property (IP)**: creations, such as inventions, literary, designs... that are protected in law, by patents, copyrights and trademarks.

- **Life Cycle Analysis (LCA)**: A method used to evaluate the environmental impact of a product through its life cycle encompassing extraction and processing of the raw materials, manufacturing, distribution, use, recycling, and final disposal.

- **Material extrusion**: An additive manufacturing technique that uses continuous filament of thermoplastic or composite material to construct 3D parts.

- **Open-source**: Denoting software for which the original source code is made freely available and may be redistributed and modified.

- **Polylactic Acid (PLA)**: A thermoplastic aliphatic polyester derived from renewable resources, such as corn-starch, tapioca roots, chips or starch, or sugarcane.

- **Prosumer**: People who produce and consume their own goods.

- **Rapid Prototyping**: A process for rapidly creating a system or part representation before final release or commercialization.

- **Thermoplastic**: A plastic polymer material that becomes pliable or moldable at a certain elevated temperature and solidifies upon cooling.

- **VAT photopolymerization**: A category of additive manufacturing (AM) processes that create 3D objects by selectively curing liquid resin through targeted light-activated polymerization.
ANNEX III. METHODOLOGY

Expert Consultations
14 experts have been interviewed from various sectors. Each consultation followed a customized interview schedule. Interviews have been analysed and transcribed qualitatively. Moreover, we also consulted and validated the policy brief with them. Please refer to the table above for more information regarding the experts.

Stakeholder Analysis
It is imperative to understand the stakeholders involved in the diffusion process of 3DP. Based on expert interviews and literature review, we identified key stakeholders with their roles and interests. Not only provided information about current actors’ dynamics, this analysis also generated essential indications for future policy recommendations.

Social Impact Assessment for Technological Innovation
The methodological framework used for assessed 3D printing has been the Social Impact Assessment (SIA) for technological innovation. The technology has been considered through a three-step analysis: (1) the description of a technological innovation; (2) the character of the influence; (3) the assessment of the impact in social environment.

ANNEX IV. THE BASICS OF 3D PRINTING

The 3DP process begins with a 3D model that is created through the use of computer-aided design (CAD) software. The CAD-based 3D model is then typically saved as a standard tessellation language (.STL) file, which is a triangulated representation of the model. Specified software then slices the model into layers and sends these instructions to the printing device. This device then creates the object by adding layers of material on top of each other until the object is created. Finally, a variety of finishing activities may be required, such as sanding, painting, polishing, etc. This last step is referred to as post-production or end-part finishing.

3D printing technologies can be classified into seven process categories - with at least 13 sub-technologies. Source: Deloitte University Press (2017). The 3D Opportunity primer: the basics of additive manufacturing.

1) In vat photopolymerization, a liquid photopolymer (i.e., plastic) in a vat is selectively cured by light-activated polymerization. The process is also referred to as light polymerization.

2) In material extrusion, thermoplastic material is fed through a heated nozzle and deposited on a build platform. The nozzle melts the material and extrudes it to form each object layer. This process continues until the part is completed.

3) In material jetting, a print head selectively deposits material on the build area. These droplets are most often comprised of photopolymers with secondary materials (e.g., wax) used to create support structures during the build process. A UV light solidifies the photopolymer material to form cured parts. Support material is removed during post-build processing.

4) In binder jetting, particles of material are selectively joined together using a liquid binding agent (e.g., glue). Inks may also be deposited in order to impart color. Once a layer is formed, a new one is created by spreading powder over the top of the object and repeating the process. This process is repeated until the object is formed. Unbound material is used to support the object being produced, thus reducing the need for support systems.

5) In powder bed fusion, particles of material (e.g., plastic, metal) are selectively fused together using a thermal energy source such as a laser. Once a layer is fused, a new one is created by spreading powder over the top of the object and repeating the process. Unfused material is used to support the object being produced, thus reducing the need for support systems.

6) In directed energy deposition, focused thermal energy is used to fuse (typically metal) material as it is being deposited. Directed energy deposition systems may employ either wire-based or powder-based approaches.

7) In sheet lamination, thin sheets of material (e.g., plastic or metal) are bonded together using a variety of methods (e.g., glue, ultrasonic welding) in order to form an object. Each new sheet of material is placed over previous layers. A laser or knife is used to cut a border around the desired part and unneeded material is removed. This process is repeated until the part is completed.
ANNEX V. A LIST OF DRIVERS OF AND BARRIERS TO 3DP ADOPTION

<table>
<thead>
<tr>
<th>Drivers of 3DP adoption</th>
<th>Barriers to (widespread) adoption of 3DP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower labour costs (less need for assembly, coordinating processes, and transport of intermediates).</td>
<td>High speed production largely impossible with common 3D printers (scalability limitations).</td>
</tr>
<tr>
<td>Lower raw material consumption (due to material efficiency gains).</td>
<td>Recapturing cost of traditional CAPEX (before potential adoption of 3DP).</td>
</tr>
<tr>
<td>Lower costs due to human errors (fewer people are involved in the process).</td>
<td>High price of raw materials (few suppliers with monopoly pricing power).</td>
</tr>
<tr>
<td>Lower inventory costs (local and on demand production).</td>
<td>Lack of knowledge and hesitance to adopt unfamiliar technologies.</td>
</tr>
<tr>
<td>Lower prototyping costs.</td>
<td>Shortfalls in the quality of printed products (inferior mechanical properties).</td>
</tr>
<tr>
<td>Lower capital expenditure (CAPEX).</td>
<td>Availability of skilled designers and engineers (young engineers lack power to change production processes; change has to come from early adopters among the experienced engineers).</td>
</tr>
<tr>
<td>Opportunities for (mass) customization.</td>
<td>Currently, mostly single material, single color, and single nozzle machines</td>
</tr>
<tr>
<td></td>
<td>Limited choice of materials</td>
</tr>
</tbody>
</table>
Blockchain Futures

Exploring the Anticipated Effects of Blockchain on Inequalities

- Blockchain Hobby: no public funding, strict regulation, no standards
- Better slow than sorry: no public funding, strict regulation, government standards
- Participatory Structure
- Exclusive Structure

4 Blockchain Scenarios

Technosociety: public funding for start-ups, liberal regulation, free educational programmes
Fast Forward: liberal regulation, industry standard, elite education programmes

Conservative Environment

Innovative Environment

Max van Deursen, Jared Gambo, Rabia Munsaf Khan, Marvin Leon Matheis, Michelle Viera, Sofie de Wit
Key Messages

- The future of blockchain is highly uncertain and the outcomes of different driving forces influence its impact on inequalities.
- Business-as-usual, is most likely to lead to an undesirable future.
- Policymakers are able to influence the future development of blockchain, described scenarios and recommendations give guidance to do so.
- Targeted measures and risk mitigation strategies should, therefore, be timely implemented.

INTRODUCTION

Initially conceived as a “decentralized ledger” capable of storing various information that is available to different users, blockchain was first applied in 2009 with the launch of the cryptocurrency Bitcoin. Since then, its usage expanded to additional application areas such as supply chains, data management and verification, healthcare and agriculture. Blockchain cannot be ignored anymore: cryptocurrencies already have a market capitalization of more than 250 billion USD3 and multiple governments, multinational corporations and NGOs have incorporated blockchain into their national or business strategy, demonstrating its increasing relevance. The blockchain system is innovative in the way in which its various parts combine to create trust and guarantees that in the traditional (financial) system would be derived from its institutions and regulations. As such, blockchain technology promises to replace trust in institutions by trust in computer code.

Current Debates

Although blockchain usage expanded to different application areas, it is still in its early implementation phase, with few mature use cases beyond cryptocurrencies. As a result, future impacts of blockchain are highly debated and uncertain: some argue that the technology might be the biggest technological breakthrough since the internet, while others consider it merely a business solution or a marketing tool. Private blockchain projects undertaken by Multinational Corporations (MNCs), such as those of IBM, are being particularly scrutinized. Private blockchains are in direct contrast with the initial concept of blockchain as a way to avoid third party oversight and distribute trust among all users, but retain cryptographic auditability function. The diverging expert opinions and its technically complex nature aggravate efforts to regulate blockchain for the common good.

BOX 1: Blockchain

Blockchain technology was initially conceived as a public decentralized ledger which relies on cryptography and self-interest to enable electronic transactions. These transactions are grouped in blocks, validated, and added to the chain of transactions by consensus amongst users. Key characteristics of the technology are its decentralized database, peer-to-peer network, security, and data transparency and immutability.

Inequality

The recently published UNDP Human Development Report 2019 stresses that technology could exacerbate existing, and create new, inequalities. Whether this also applies to blockchain is a crucial question, which so far has rarely been addressed. Most research focuses on blockchain applications in cryptocurrency, such as Bitcoin, and points to the fact that wealth is accumulated with 4% of users holding 97% of bitcoins. Since blockchain is developing rapidly and expanding to new application areas, it is ever more important to anticipate its effects on inequality and actively make decisions that unlock the potential of blockchain to reduce, rather than reinforce, inequality. This policy brief examines the anticipated effects of blockchain on inequality and identifies key action points. In particular, this brief focuses on the application of blockchain in Global Supply Chains (GSCs), since blockchain applications within GSCs are currently increasing. GSCs span the whole world, from developed to developing countries, from powerful MNCs to impoverished smallholders. The global reach and involvement of different actors make GSCs an important area of study, since the impact of applying blockchain within GSCs on inequalities is

BOX 2: Case study - Blockchain in the Shrimp Aquaculture Supply Chain

The application of blockchain is emerging in Aquaculture, particularly within fisheries in the Global North and large scale shrimp exporters in the Global South. Recently, a group of shrimp exporting companies in South America has created a private blockchain initiative called SSP - Sustainable Shrimp Partnership, a partnership with the IBM Food Trust Network. Their goal is to provide more traceability via blockchain technology to verify product authenticity and transparency of environmental, social, and governance performance information. Smart contracts between farmers and food suppliers help meet market demands and provide food safety while addressing environmental sustainability. However, interviews with experts raised skepticism about the worthiness of the technology as concerns about vendor lock-in, technology and data governance, and the practical implementation of private blockchains still need to be addressed. For now, blockchain applications in shrimp aquaculture supply chains are mostly international business-to-business solutions to improve the reliability of seafood information. Such reliability is achieved through harmonized product requirements and standardized technical specifications on how to share verifiable data in interoperable traceability systems.
highly uncertain, and could be used as an illustration of bigger risks associated with blockchain.

Roadmap
In order to anticipate the effects of blockchain on inequality, this policy brief outlines four different future scenarios. These scenarios are exploratory, meaning that they entail a range of possible consequences of strategic decisions made by the industry, policy makers, or consumers. Based on examination of these scenarios, different effects on inequalities are identified which serve to decide which scenario is most desirable. Finally, a list of policy recommendations are provided in order to reach a desirable scenario, while mitigating the associated risks.

FROM PRESENT TO BLOCKCHAIN FUTURES
The following four future scenarios are strategic exploratory scenarios. This means that each scenario is equally likely and that policy makers can, to a certain extent, influence which scenario becomes reality. All scenarios are neutral meaning that one is not necessarily preferred over another. The scenarios and identified driving forces are based on expert interviews and extensive literature review (see Annex I, IV and V). Two main driving forces serve as the basis for the scenarios. First, technological development, which refers to the future socioeconomic environment, including investment, innovation, and government regulation. And second, decision making in the blockchain, which refers to who has the power to set the rules of the blockchain. The initial conception of blockchain as a “decentralized ledger” and its current examples in Ethereum and Bitcoin, lead many to imagine permissionless blockchains to become the future standard. However, others argue that private, permissioned blockchains, such as Tradelens, will eventually prevail.

Based on these key driving forces, the following scenarios have been designed: (1) Techno Society, (2) Fast Forward, (3) Better Slow than Sorry, and (4) Blockchain Hobby. The scenarios envision how the world might look in 10 to 20 years from now, particularly in relation to inequality. Inequality is subdivided into three concepts: access, design, and outcome. Inequality of access refers to divergence of access to blockchain technology; this divergence can be shaped by many factors including affordability and skills. Inequality of design refers to differences in ability to influence the technical design of blockchain systems. Lastly, there is a broad category of inequality of outcome resulting from the former inequalities of access and design. For example, inequality in access might lead to inequality of income. The inequalities as described above can affect different actors. Special attention is given to inequalities between large and small companies, vendors and consumers, people with high and low financial means, and developed and developing countries. Finally, the scenarios are portrayed presuming the world moves uniformly towards one scenario, yet in reality different scenarios are likely to play out simultaneously in different parts of the world.

SCENARIO 1: TECHNO SOCIETY
In this scenario blockchains have become part of everyday life, much like the internet is now. Blockchains can be used, managed and created by anyone; the power to set and change the operating rules of the blockchain is distributed among all participants. The innovative environment is characterized by considerable funding and subsidies for start-ups. Moreover, regulation allows for experimentation. However, due to the existence of many different, dynamic blockchain protocols, it is difficult for governments to design and enforce effective regulation. One critical aspect in this scenario is the high energy consumption due to the need of extensive computational power and low interoperability between different blockchain solutions.

The blockchains in this scenario are public and permissionless, and thus allow anyone to participate. This participation is enabled by blockchain educational material that is made publicly available and integrated into education curricula, fostering low inequalities in access and design. Inequalities of outcome are moderate. The participatory ownership of the blockchain guards against modifications, such as participation fees, which are disadvantageous to users. There will be a diversity of start-ups building solutions on top of the blockchains such as data analytics, and fewer inequalities between small and big companies. Yet, this environment is also volatile. Regulations are often ineffective and user protection is not always guaranteed which may lead to frauds for those who are less knowledgeable.

With regards to GSCs, all participants have sufficient digital capabilities to use blockchains, including smallholders, who gain increased access to regional and global markets. Yet, low interoperability poses an impediment for efficient information exchange between different actors in supply chains, slightly reducing its adoption. Nevertheless, blockchain is increasingly embedded in certification schemes to source products responsibly and achieve corporate social responsibility goals. This is possible because the digital representation of physical goods, so-called digital twins, are accurate and reliable.

SCENARIO 2: FAST FORWARD
In this scenario a few powerful actors, mainly MNCs, set the stage. They push for the diffusion and adoption of blockchains, leading to broad applications. MNCs design the protocols of the blockchains and provide a simple interface so the technology is easily accessible to all users. To drive innovation, the government actively supports MNCs through financial and regulatory processes.

Inequality of access is moderate: MNCs help make blockchain available to the public while also introducing a
fee for their services, thereby systematically excluding those with less financial means. Inequality of design is high because MNCs exclusively design and develop the protocols of the blockchain. These actors have sufficient capital to contract high-skilled IT professionals. Furthermore, MNCs, most of which are located in the Global North, design all blockchains according to their interests. Inequality of outcome is high. Those with sufficient financial means are the first to adopt blockchains, giving those who are already better off access to new opportunities such as cheap money transfers. In some situations vendor lock-ins occur, where those in charge of the blockchain steadily increase their markup, leading to inequality between the vendor and their consumers.

In GSCs, MNCs promote the use of blockchain to optimize efficiency and accelerate, or even replace complex, paper-intensive processes through blockchain solutions. Smallholders may not be able to meet the standards and requirements to join a MNC-owned blockchain due to data entry standards and associated adjustment costs, potentially forcing them out of business. Moreover, most blockchains are designed in such a way that data flows from the small-scale producer to the large-scale retailer or consumer, augmenting, rather than reducing, existing asymmetries of information and power in GSCs.

**SCENARIO 3: BETTER SLOW THAN SORRY**

This scenario is characterized by its conservative environment, in which most governments take a cautious stance towards promoting innovation, widespread diffusion, and adoption of blockchain due to risk aversion and an observant attitude towards new technologies. Slow innovation and a low adoption rate, in combination with exclusive decision making in the blockchain, ensure effective government regulation, user protection, interoperability, and data quality. As a result, fraud and system breakdowns rarely occur and security on the blockchain is high.

However, inequality of access is also high: only powerful actors are able to comply with the very strict regulations. Consequently, existing inequalities in terms of access to new technologies are enhanced with opportunities between large and small companies varying greatly. Inequality of design is moderate. Although MNCs design the blockchain systems, governments clearly set the boundaries, and can thus safeguard users’ interests. Business practices which disregard user interest, such as data privacy, will not be allowed. Inequality of outcome is low due to strict and protective regulations, in combination with a relatively low adoption of blockchain. However, there is a risk of inequalities between large and small companies because mostly the former have access. This could potentially lead to a cluster of MNCs that efficiently share information on the blockchain, outcompeting smaller companies.

Blockchain application in GSCs is limited to a few cases in which highly valuable goods, such as diamonds, are traded, or in which MNCs are the central players. In the latter, blockchain is mostly used to optimize business processes. In general, very few smallholder farmers have access to blockchain applications.

**SCENARIO 4: BLOCKCHAIN HOBBY**

In this scenario the conservative environment in combination with a lack of interest from the private sector has hampered the development and diffusion of blockchain. Some enthusiasts and specialists use blockchain, but this technology has not become “the new internet”. Yet, the blockchains that do exist can be used, managed, and created by anyone who has sufficient skills to do so.

Although decision making in the blockchain is participatory, inequality of access is moderate and inequality of design is high. This is caused by the fact that very few people are knowledgeable and interested enough to participate: digital capabilities are low. Although there is divergence in terms of access and design, inequality of outcome is low. This has very little impact on outcomes because blockchain technology is not widely adopted and remains immature.

Blockchain usage to manage GSCs has proven to be less effective than alternative technologies. As a result, companies prefer to use existing systems such as centralized databases to manage their supply chain. Inequalities between developing and developed countries are unaffected by blockchain in this scenario. Most smallholders are not aware of blockchain technology since it is not widely used or beneficial to them.

**RECOMMENDATIONS**

The four scenarios presented above all come with their own characteristics, benefits, and risks which translate into low, moderate or high inequalities (see table 1). In order to steer the development of blockchain into a desired direction, three essential steps are proposed. Policymakers first need to decide on the most favorable scenario, then analyze which measures ought to be taken to reach the scenario of choice, and lastly, develop instruments in order to mitigate the risks associated with the respective scenario. Whichever scenario is most desirable is up to the policy maker. In the case that equality is valued the highest, a target that is explicitly postulated in SDG 10, policymakers should aim for the “Techno Society” scenario. In a “Techno Society” the inequality of access and design are both low and inequality of outcome is moderate. In order
Table 1: Assessment of inequalities in the four blockchain scenarios. Each scenario has an inequality score that is either low, moderate, or high. The single scores of the three analysed inequalities are summed in a total score. The lower the score the more blockchain contributes to improve to steer the development of blockchain technology towards this scenario the following targeted measures and risk mitigation strategies should be taken into account. The targeted measures contain references to examples and best practices.

<table>
<thead>
<tr>
<th>How to achieve the scenario?</th>
<th>Techno society</th>
<th>Fast forward</th>
<th>Better slow than sorry</th>
<th>Blockchain hobby</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inequality of access</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
<td>Moderate</td>
</tr>
<tr>
<td>Inequality of design</td>
<td>Low</td>
<td>High</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>Inequality of outcomes</td>
<td>Moderate</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

**Targeted measures**
- National and regional government entities should allocate funding to innovative start-ups and small and medium-sized enterprises that innovate in the field of blockchain. For example, the Korean government has a special fund to support blockchain start-ups.\(^{23,24}\)
- National and regional government entities should adopt liberal and innovative regulation,\(^{25}\) including regulatory sandboxes that allow for experimentation.\(^{26}\)
- National and regional government entities should make use of, and/or develop data protected public blockchains to deliver government services to citizens.\(^{26}\) For example,莫斯科’s public administration is building government services on top of the Ethereum public blockchain.\(^{27,28}\)
- National governments and educational institutions should make blockchain an integral part of education curricula to enable potential participation for all citizens.\(^{29}\) For example, France has announced to add a module on Bitcoin to high school education.\(^{30}\) Moreover, online learning programs focusing blockchain should be made freely available for the public.
- National and regional government entities should empower youth, especially in developing countries, to participate in blockchain development by making them a focal point in each of the measures stated above.

**Risk Mitigation Strategies**
- Increase capacities of existing national and regional governmental bodies that regulate and oversee blockchains, or create new ones in order to keep pace with the disruptive and rapid technological development and in order to reduce the risk for scams and assure blockchain quality.\(^{31}\)
- Promote and support the development of interledger solutions in order to increase the interoperability of different systems.\(^{32}\)
- Foster the development of energy-efficient blockchain technology to account for increasing environmental concerns due to high energy consumption.\(^{33}\)
BIBLIOGRAPHY

# Annex I. Consulted Experts

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Position</th>
<th>Interview Date</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bolt, Martijn</td>
<td>The Hague University of Applied Sciences</td>
<td>Lecturer</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Brouwers, Jan</td>
<td>Wageningen Centre for Development Innovation</td>
<td>Senior advisor</td>
<td>11/12/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Burke, Thomas</td>
<td>Institute of Food Technologists</td>
<td>Food Scientist</td>
<td>12/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Bruin, Louis de</td>
<td>IBM</td>
<td>Blockchain Thought Leader Europe</td>
<td>20/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Vos, Jordi de</td>
<td>Circularise</td>
<td>Co-Founder</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Debi-Tewar, i Sharvan</td>
<td>Circularise</td>
<td>Programer</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Dijk, Bas van</td>
<td>Port of Rotterdam</td>
<td>Advisor, Strategic Finance</td>
<td>22/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Ee, Rudolf van</td>
<td>Blockchain Netherlands</td>
<td>Founder</td>
<td>20/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Ellul, Joshua</td>
<td>University of Malta</td>
<td>Senior Lecturer, Chairman</td>
<td>22/11/2019</td>
<td>Malta</td>
</tr>
<tr>
<td>Gijzel, Rob van</td>
<td>Intelligent Community Forum Foundation, Dutch Blockchain Coalition</td>
<td>Chairman, Member</td>
<td>22/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Gils Marten, van</td>
<td>Fairfood</td>
<td>Programme manager fair tech</td>
<td>25/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Godar, Javier</td>
<td>Stockholm Environment Institute</td>
<td>Senior Research Fellow</td>
<td>19/11/2019</td>
<td>Spain</td>
</tr>
<tr>
<td>Ileri, Can Umut</td>
<td>TU Delft</td>
<td>Postdoc</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Ishmaev, Georgy</td>
<td>TU Delft</td>
<td>Postdoc</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Kloppenburg, Sanneke</td>
<td>Wageningen University</td>
<td>Assistant Professor</td>
<td>26/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Kroft, Ad</td>
<td>Dutch Blockchain Coalition</td>
<td>Program Manager</td>
<td>25/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Kruk, Sake</td>
<td>Wageningen University</td>
<td>PhD researcher</td>
<td>26/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Mba Wright, Mark</td>
<td>Iowa State University</td>
<td>Assistant Professor</td>
<td>19/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Ndemo, Bitange</td>
<td>University of Nairobi, UNISOT</td>
<td>Professor, Chairman</td>
<td>16/11/2019</td>
<td>Kenya</td>
</tr>
<tr>
<td>Niessson Stefan</td>
<td>UNISOT</td>
<td>Founder</td>
<td>29/11/2019</td>
<td>Sweden</td>
</tr>
<tr>
<td>Rijmenam, Mark van</td>
<td>Datafloq</td>
<td>Founder</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Roos, Stefanie</td>
<td>TU Delft</td>
<td>Assistant Professor</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Wassenaer, Lan van</td>
<td>Wageningen University</td>
<td>Senior Scientist</td>
<td>15/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Professor, Chair</td>
<td>18/10/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Associate Professor</td>
<td>07/10/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Associate Professor</td>
<td>10/10/2019</td>
<td>Canada</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Software Developer</td>
<td>20/10/2019</td>
<td>Pakistan</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>PhD Researcher</td>
<td>28/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>IT Business Executive</td>
<td>17/10/2019</td>
<td>Pakistan</td>
</tr>
</tbody>
</table>
ANNEX II. GLOSSARY

- **Cryptography**: a method of protecting information and communications through the use of codes so that only those for whom the information is intended can read and process it. 

- **Digital twin**: a digital replica of a physical entity.

- **Distributed ledger technology**: a digital system for recording the transaction of assets in which the transactions and their details are recorded in multiple places at the same time.

- **Permissioned blockchain**: a blockchain with restrictions in place on who is allowed to participate in the network. These can be at the level of seeing data, writing data and contributing to the mining process.

- **Private blockchain**: an invitation-only network governed by a single entity, allowing organizations to employ distributed ledger technology without making data public.

- **Protocol**: the source code of a program. For example, the source code of a blockchain might set the maximum amount of transactions in one block on the blockchain.

- **Public blockchain**: public blockchains have no access restrictions. Everyone can participate in the network and contribute to validation. Validators are incentivized.

- **Ump ermissioned blockchain**: see public blockchain.
For this policy brief, 25 experts from different fields and sectors were consulted through semi-structured interviews. All interviews were transcribed and analyzed using inductive thematic analysis. A broad literature review, including academic and grey literature, based on keyword searches in the domains blockchain, global supply chain and smallholders added into the thematic analysis. Themes were condensed into driving forces and micro scenarios (see Annex IV and V) by analyzing which themes will be most important and most uncertain in determining the future development of blockchain. The two most important micro scenarios were identified as the axes, on which the scenarios were consequently build. The other micro scenarios served as a guidance in developing the four scenarios. The scenarios are strategic exploratory scenarios. This means that each scenario is equally likely and that policy makers can, to a certain extent, influence which scenario becomes reality. Besides providing knowledge, some experts were also consulted for feedback on the policy brief. A full list of interviewed experts can be found in Annex I.
Annex IV. Driving Forces Definitions

Decision Making in the Blockchain: the distribution of power to make and change the operating rules of the blockchain
- Participatory: all actors have the right to participate in decision making
- Exclusive: few actors have the right to participate in decision making

Technological Development: the process of the development of blockchain technology, including innovation, investment in RD&D, and establishment of a conducive regulation by governments
- Innovative: high innovation rate, high investment in RD&D, conducive regulation
- Conservative: low innovation, low investment in RD&D, non-conducive regulation

Scale of Adoption: the level of diffusion and adoption of blockchain solutions and applications
- Low: regional scale of adoption and low amount of users
- High: global scale of adoption and high amount of users

Interoperability: the ability of different blockchain applications to operate in conjunction with one another (same technical standards)
- Low: fragmented system with different technical standards
- High: integrated system with unified technical standards

Willingness to Share Data: consent to share (private) data on the blockchain
- Low: not willing to share data
- High: willing to share data

User Protection: existence of measures that assure that all participants in the blockchain (including consumers) have benefits from its usage
- Low: no or few measurements for user protection are in place, it cannot be guaranteed
- High: many measurements for user protection are in place, in can be guaranteed

Data Quality: the extent to which the pieces of information on the blockchain correspond to what they represent in the real world
- Low: the data hardly corresponds to the real world
- High: the data corresponds to the real world

Digital Capabilities: level of capabilities to use the blockchain, program the blockchain and regulate the blockchain
- Low: knowledge and understanding of blockchain is not widespread
- High: knowledge and understanding of blockchain is widespread

Requirements of Blockchain Usage: means or capabilities, including internet access, required technical devices, electricity and digital literacy, a user of blockchains needs
- Low: almost no means or capabilities are needed to use blockchains
- High: many means or capabilities are needed to use blockchains
ANNEX V. DIAGRAMS

Figure 1: Overview of four blockchain scenarios with associated key risks and benefits. These scenarios are based on interviews with 25 experts.
Figure 2: Overview of micro-scenarios. Micro scenarios formed the base of the blockchain futures scenarios and are based on all identified driving forces.

**Scenario 1**

**Techno Society**

**Participatory**

- **Decision-Making in the Blockchain**
- **Technological Development**
- **Scale of Adoption**
- **Interoperability**
- **Willingness to Share Data**
- **User Protection**
- **Data Quality**
- **Digital Capabilities**
- **Requirements to Use Blockchain**

**Innovative**

**Conservative**

**Scenario 2**

**Fast Forward**

**Participatory**

- **Decision-Making in the Blockchain**
- **Technological Development**
- **Scale of Adoption**
- **Interoperability**
- **Willingness to Share Data**
- **User Protection**
- **Data Quality**
- **Digital Capabilities**
- **Requirements to Use Blockchain**

**Innovative**

**Conservative**

**Exclusive**
SCENARIO 3
BETTER SLOW THAN SORRY

SCENARIO 4
BLOCKCHAIN HOBBY
Big Data in Agriculture

Towards Collaborative Digital Agriculture in the Developing World

Current Situation
- lack of technological enabling environment, low quality services for smallholders

Leverage Points
- Multisectoral Involvement
  - Public
  - Private
  - Civil Society
  - Farmers

- Open Data
  - Closed
  - Shared
  - Open

State Level
- economic, technological and information dependence

Farmer Level
- lack of inclusion
- needs driven innovation, empowerment of farmers
- local economic activity, diversity of information
KEY MESSAGES

- Through the promise of higher yields and improved efficiency, digital agriculture is expected to enhance food security, economic growth, and climate resilience in the developing world.
- The spread of this technology in the developing world has been limited by lack of basic infrastructure and digital data, uncoordinated efforts by the private and public sectors, and reluctance to share data.
- A tendency towards market monopolies in digital technologies poses the threat of technological, economic, and information dependence on developed countries, as well as unequal access to the benefits of technologies among farmers.
- The movement towards open data and the inclusion of farmers in the development of technology could mitigate associated risks by stimulating the local economy and ensuring bottom-up, need-driven innovation.

INTRODUCTION

Big data is an emerging field where innovative technology offers new ways of extracting value from digital data and is being increasingly applied in the agricultural sector, specifically in digital agriculture. Digital agriculture employs big data within the agricultural value chain to improve food production and help farmers make more informed and appropriate decisions. By entangling agricultural value chains with the value chain of data, this technology holds great potential in supporting the achievement of the Sustainable Development Goals (SDGs), specifically with regards to hunger eradication, economic growth, and climate resilience (see ANNEX 4).

SDG 2: Zero Hunger: It is estimated that a 60% increase in food supply is needed by 2050 to feed the growing world population. Through the promise of improved efficiency throughout value chains and higher yields, digital agriculture can reduce associated production strains, especially in the developing world where losses in production are a particularly significant issue.

SDG 8: Decent Work and Economic Growth: Digitalization of agriculture is also expected to boost economic productivity and growth, while at the same time creating demand for high-skilled workers in the agritech sector. It is furthermore expected to stimulate entrepreneurship and creativity and make strides towards SDG 8.

SDG 13: Climate Action: Digital agriculture enables informed decision making for farmers, contributing to both climate mitigation and adaptation through the optimization of resources and increased resilience in the context of climate change. Regardless of its potential, digital agriculture comes with its own set of challenges and questions that need to be addressed. Firstly, unequal access to digital agriculture technologies due to the lack of an enabling environment reduces their impact on the developing world. Secondly, the so-called networked nature of digital technologies gives rise to feedback loops in which higher amounts of data collected empower a few actors to provide better services and in turn collect even more data, effectively eliminating the competition. This winner-takes-all effect enables a few actors to become market gatekeepers, with potentially negative impacts on the distribution of the value produced with data. Finally, the lack of inclusion of farmers and civil society in the development and implementation of the technology by corporations raises issues of data misuse and could lead to unequal distribution of benefits, perpetuating a productivist agricultural model.

The focus of this policy brief will be on smallholder farmers in the developing world. Smallholder farmers are responsible for the majority of the local food supply in the regions with the most rapidly growing populations in the world and are recognized to increase the resilience of the agricultural system by maintaining the genetic diversity of the food supply, mitigating risks of nutritional deficiencies and ecosystem degradation. This brief will analyze current issues and future risks for states and smallholder farmers in the developing world. The movement towards an open data ecosystem and the involvement of farmers and civil society in multi-sectoral partnerships are then identified as two leverage points that policymakers can use to ensure an inclusive development of digital agriculture and maximize its impact on sustainable development.

BOX 1: The data value chain

Value from data is created through a chain of processes: data generation, collection, curation and storage, analysis, and usage or exchange. After being generated and recorded, data must be curated and validated before it can be effectively used, stored, analyzed, and finally, used or exchanged as information for decisions and services. Digital agriculture relies upon data from widely different sources, including personal information of farmers, farm location and size, crop information, weather data, and financial instruments. The data can be crowdsourced through mobile phones and social media, or collected with tools like drones, satellites, and sensors. A wide range of agricultural services and products can be developed based on this data, ranging from advisory and information services to market linkages and financial access services. Currently, advisory services are being developed to help smallholder farmers make informed decisions about their farming practices (e.g. concerning weather conditions).
CURRENT ISSUES
While it is impossible to paint a comprehensive picture of the current state of digital agriculture in the developing world, there are consistent obstacles that spread beyond borders. Many countries in the developing world lack technological enabling environments that make the generation and collection of data possible, including basic infrastructure such as access to the internet and smartphones, weather forecasting, and satellite-imaging technologies.1

As a result, data is often lacking in developing countries.12 Data generation and collection are often carried out by a wide range of actors including private companies, development projects, and governments in a fragmented effort, resulting in the duplication of data and a decrease in the value and shareability of the ensuing datasets. Moreover, companies are reluctant to share their data, for fear of losing their competitive advantage consequently “locking” data into companies.13,14 Sharing data is also obstructed when there are no standards for data curation in place, as data then fails to become interoperable and cannot be exchanged over systems and devices.5 These factors strengthen the barriers that obstruct the sharing of datasets, resulting in a lack of data integration and reducing the value that can be generated through analysis.5 The lack of data and its fragmentation affect the number of services that are offered to farmers. Furthermore, the services that are developed are often ineffective and do not align with the needs and problems faced by farmers. The quality and reliability of the services also vary widely, sometimes resulting in a loss of trust in the technology. In this context, the ability of agricultural data technologies to contribute to the aforementioned SDGs through poverty reduction, rural development, and climate adaptation for the most vulnerable, is drastically reduced.

FUTURE RISKS
Private companies are beginning to take advantage of the rapid spread of technology and increasing levels of connectivity in the developing world to enter markets faster than local governments. In this context, large agricultural multinational corporations (MNCs) enjoy the greatest opportunity to increase insight, quality, scale of services, and thus, profits. They are favored due to their extensive datasets, expertise, ability to invest, and large-scale sustainable business models.15 While this could provide benefits by quickly and efficiently reducing the technological gap between the developing and developed world, it could also pose many threats at the state and farmer level.

STATE LEVEL RISKS
Big MNCs can act as market gatekeepers by monopolizing proprietary data and by preventing smaller companies from developing effective technologies and competing in the market. In this scenario, local companies would be particularly affected, entrepreneurship and innovation in the developing world would be stifled, and the promise of a digitalization of the economy would not materialize. The technological and economic dependence of the agricultural sector on the developed world would be reinforced by positive feedback loops intrinsic to the data. This would be especially relevant in rural areas where “farmers become franchisers” of big agricultural companies that supply inputs (seeds, tools, agrochemicals) and collect produced outputs (agricultural products and data). Eventually, this could lead to a new kind of information dependence. In a context in which agricultural data is lacking, foreign MNCs could become the only reliable source of information and obtain a great influence on policy decision making.

SMALLHOLDER-FARMER LEVEL RISKS
A profit-driven approach to innovation by MNCs can lead to a lack of inclusion in the development and implementation of digital agricultural technologies which are often only tailored to large-scale farming practices. This leads to unequal access to these technologies, due to their high costs and ineffectiveness when applied to different farming contexts. Precision agriculture technologies, for example, have selectively favored large scale over small scale farmers in the UK, USA, and Canada. In turn, unequal access promotes an overrepresentation of large-scale agronomic farming in the data collected by digital agriculture technologies, potentially affecting policy decisions and further perpetuating the dominant productivist framing of agriculture. This agricultural system is often criticized for its negative environmental, health, and socio-economic impacts and its potential for alleviating hunger has also been contested.6 Finally, privacy issues and data misuse are exacerbated when the data consumer (private company) is directly linked with the data producer (farmer) and no aggregation and anonymization of data is carried out. The risks for the farmer can vary from the monetization of its personal data through advertisement, to the threat of it being used to favor competitors.

Box 2: Current Problems & Future Risks

<table>
<thead>
<tr>
<th>State level</th>
<th>Current problems</th>
<th>Future risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lacking technological enabling environment</td>
<td>• Lack of basic infrastructure &amp; &amp; lack of digital data</td>
<td>• Economic dependence</td>
</tr>
<tr>
<td>• Uncoordinated efforts to collect data</td>
<td>• Technological dependence</td>
<td></td>
</tr>
<tr>
<td>• Reluctance to sharing data</td>
<td>• Information dependence</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Farmers’ level</th>
<th>Low quality services for smallholders</th>
<th>Lack inclusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Few and ineffective services</td>
<td>• Unequal access to technology</td>
<td></td>
</tr>
<tr>
<td>• Loss of trust in technology by farmers</td>
<td>• Risk of data misuse</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Perpetuation of productivist framing of agriculture</td>
<td></td>
</tr>
</tbody>
</table>
LEVERAGE POINTS

Key leverage points have been identified that can contribute to develop a technological enabling environment, increase the quality of services provided to farmers, and to reduce the accompanying risks of market monopolies in the agricultural sector.

The movement towards an open data ecosystem also poses some risks. Firstly, while barriers to market access would be lowered, unequal data-processing capacity could still pose a threat. The computational advantage enjoyed by big corporations could lead to imbalances in the ability to provide services and more power centralization in the market. A similar scenario could exacerbate privacy issues related to data collection: in an open data scenario non-anonymized personal information could be used against individuals and organizations. For this reason, some call for a selective opening of data. Data would therefore fall in a spectrum ranging from closed to completely open (Annex 5 - The Data Spectrum, Open Data Institute). Others advocate for data to be shared only with specific actors for the purpose of providing services, connecting information, and contributing to research. Voluntary data sharing agreements such as codes of conduct between the provider and the user of data have also emerged as effective solutions to legislative gaps in this field. These codes can replace currently used private data contracts or licensing agreements, which are normally very complex and on which data producers have very little negotiating power.

2. Multisectoral Involvement

Partnerships are considered to play a crucial role in sustainable development, broadly described by SDG 17 as “promoting the development of environmentally sound technologies to the developing world” (target 17.7). However, critics argue that the vast majority of partnerships do not deliver effective development interventions due to the lack of involvement of civil society. In digital agriculture, this is exemplified by the lack of inclusion of farmers in the development and implementation of new technologies, resulting in unequal access to the benefits and risks of data misuse. Despite their central role as producers of crowdsourced data and end-consumers of the services, farmers are often only seen as end-users, rather than as participants by service providers.

A potential solution is identified in multisectoral involvement in partnerships, where farmer representatives such as farmer organizations, extension agents, and cooperatives could come together to act as farmer aggregators (FAs) and collaborate with the private and the public sector.

Firstly, FAs could act as centers for the aggregation and anonymization of data, thereby preserving the privacy of the farmers and reducing the risk of their data being used against them. In this sense, FAs would become trust centers for farmers, allowing them to jointly negotiate terms and conditions for the adoption of new technologies and usage of the data they decide to share. At the same time, the aggregating role of FAs could be very valuable for governmental and private actors. Farmer organizations are...
often the only repository of certain sets of data that are needed for the development of new digital agricultural technologies, such as farmers’ locations, crop varieties, and farm size. This could prove to be extremely valuable for the digital profiling of farmers, especially in marginalized areas.

Secondly, multisectoral partnerships could provide the link between farmers and the private sector that is necessary to ensure bottom-up, need-driven innovation. As mentioned, experts believe that innovation only benefits actors that are directly involved in its development. In similar partnerships, these aggregating organizations could facilitate smallholder farmers involvement in the design of digital agricultural services. This inclusive approach to innovation could result in technologies that are tailored to the needs of the farmer, providing the private sector with a sustainable business model and alleviating the tension between governments seeking to regulate innovation of the private sector.

Finally, by shifting from market-push to market-pull, these partnerships would prevent the promulgation of a single dominant agricultural paradigm. Rather, they will encourage diversity, since different technologies could be developed for different farming models.

While there is optimism towards the role that FAs could play in partnerships for development, some experts are wary. Potential FAs such as farmer organizations are far from being a homogeneous group: they differ widely in size, power in the agricultural value chains, and the interests that they represent. Empowering them to play a central role in developing more inclusive digital agriculture solutions therefore brings the risk of exacerbating existing power inequalities, potentially neglecting the interests of the weakest. Moreover, FAs represent farmers who are often not the most marginalized actors in rural societies. Landless laborers and unmarried women, for example, would not be represented, despite their role in agricultural value chains. Partnerships that aim to be inclusive and successfully reduce inequalities need to include the broadest possible range of actors from civil society, with a special eye for the most marginalized.

![RECOMMENDATIONS]

❖ With regards to need-driven innovation and empowerment of farmers, the United Nations and government sectors should consider stimulating farmer-centric multi-sectoral partnerships in digital agriculture through:
  • Incentivizing the formation of partnerships by informing the stakeholders of their benefits through promotion programs.
  • Stimulate the aggregation of (smallholder) farmers in organizations and provide these new and existing aggregations with needed information to participate in the partnerships.
  • Ensuring the diversity of farmers is equally represented through inclusive partnerships of smallholder farmer aggregators.

❖ In order to increase local economic activity and the diversity of information, the United Nations and governments should aim to increase open data through:
  • Incentivizing the sharing of data by informing stakeholders of the benefits through promotion programs.
  • Creating central open data libraries to lower digital agriculture market barriers to facilitate local companies’ participation.
  • Capacity development to enable the use and development of data-based services by local tech companies and farmers.

❖ In order to avoid the exploitation of sensitive data, governments should consider:
  • Developing a stronger legislative framework for the selective sharing of data and encouraging the use of codes of conduct to increase transparency of data usage.
5. GSMA, and ATKearney. 2018. The Data Value Chain.
7. Salami, Adeleke, Abdul B Kamara, and Zuzana Brixiova. 2010. Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities.
11. Pye-Smith, Charley. 2015. Climate Solutions That Work for Farmers: Success Stories From the Field. Wageningen, Netherlands. CTA.
<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Position</th>
<th>Interview Date</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addison, Chris</td>
<td>CTA</td>
<td>Senior Programme Coordinator</td>
<td>25/11/2019</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Ceccarelli, Tomaso</td>
<td>Wageningen University</td>
<td>Researcher</td>
<td>22/11/2019</td>
<td>Italy</td>
</tr>
<tr>
<td>Janssen, Sander</td>
<td>Wageningen University</td>
<td>Team leader Earth Informatics</td>
<td>22/11/19</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Maredia, Karim</td>
<td>Michigan State University</td>
<td>Professor and Senior Associate to the Dean</td>
<td>27/11/2019</td>
<td>India</td>
</tr>
<tr>
<td>Shanoyan, Aleksan</td>
<td>Kansas State University</td>
<td>Associate Professor</td>
<td>25/11/2019</td>
<td>Armenia</td>
</tr>
<tr>
<td>Unwin, Tim</td>
<td>UNESCO</td>
<td>UNESCO Chairholder in ICT for development</td>
<td>05/12/2019</td>
<td>United Kingdom</td>
</tr>
<tr>
<td>Valeria, Pesce</td>
<td>FAO</td>
<td>Information Management Specialist</td>
<td>29/11/2019</td>
<td>Italy</td>
</tr>
<tr>
<td>Wolfert, Sjaak</td>
<td>Wageningen University</td>
<td>Senior Scientist</td>
<td>22/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Zwart, Nikolet</td>
<td>Bio Legal</td>
<td>Lawyer</td>
<td>26/11/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Project Manager in Open Data</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Anonymous</td>
<td>One Acre Fund</td>
<td>Co-Director, Recruitment at One Acre Fund</td>
<td>28/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Rabobank</td>
<td>Senior Project manager</td>
<td>02/12/19</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>University Professor of Competition Law</td>
<td>03/12/2019</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Team Leader in an international organization for agricultural and rural development.</td>
<td>25/11/2019</td>
<td>Ghana</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Project Coordinator in an international organization for agricultural and rural development</td>
<td>25/11/2019</td>
<td>Zimbabwe</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Senior Researcher</td>
<td>22/11/19</td>
<td>Netherlands</td>
</tr>
<tr>
<td>Anonymous</td>
<td>Anonymous</td>
<td>Professor of international and European environmental law</td>
<td>21/11/2019</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>
ANNEX II. GLOSSARY

- **Big Data**: is a field which offers new ways to extract value from data that are characterized to be high in volume (large scales of data), velocity (stream of data coming in, in high-frequency) and variety (of differing syntactic formats).

- **Developing countries**: are low-, lower middle-, and lower middle-income countries in the World Bank categorization of 2014.

- **Smallholder farmers**: are individuals who produce crops or livestock on two or fewer hectares of land.

- **Farmer Aggregator (FA)**: is an organization which represents farmers. This one can negotiate with other stakeholders involved in digital agriculture on behalf of farmers.

- **Farmer cooperatives**: are organizations of farmers which is owned and run jointly by its members, who share the profits or benefits often used for marketing their products or buying supplies.

- **Data-driven agriculture**: is the use of big data to help on-farm decision making.

- **Data-driven technologies**: refer to intelligent machines who are able to process and analyze big data.

- **Data based services**: are services that are driven by data-such as advisory & information services, market linkages, supply chain management, financial access and macro agricultural intelligence.

- **Extension services**: are middle-man organizations, between farmers and bodies that provide services to farmers (e.g. technical advice supplies them with the necessary inputs (seeds)).

- **Digital Agriculture**: is the use of new and advanced technologies that are integrated into one system.

- **Networked nature**: is the ability of data technologies to empower a few actors, through a feedback loop of data collection which enable them to provide better services and in turn collect even more data, eliminating the competition.

- **Market gatekeeper**: are actors that are able to influence market entry barriers and thus enable/disable others to participate in the market.

- **Multisectoral involvement/partnerships**: refers to the cross collaboration between groups (e.g., government, civil society, and private sector) and sectors (e.g., health, environment, and economy).
ANNEX III. METHODOLOGY

Interview Analysis
For this policy brief, 17 experts from different fields and sectors were consulted through structured interviews. Interviews were then transcribed and collected data analyzed through the inductive thematic analysis. Besides providing knowledge, some experts were also consulted for feedback on the policy brief. A full list of interviewed experts can be found in the table below.

Scenario Analysis
The data collected through interviews helped identify the following drivers: regulations, access to service, private and public sector, market, transparency, public perception and knowledge. This policy brief used predictive scenarios to analyze how the aforementioned drivers might influence the future development of Big Data in the agricultural sector in the developing world. This scenario analysis was not included but influenced this work.
ANNEX IV. OPEN DATA SPECTRUM

The Data Spectrum: Agriculture

Sub-Saharan Africa and South Asia focus

Internal access
- Employment contract + policies
- Smallholder finances

Named access
- Explicitly assigned by contract
- Pesticide application permits

Group-based access
- Via authentication
- Reports of crop disease

Public access
- Licence that limits use
- Patented pesticide formulas

Anyone
- Open licence
- Earth observations

Closed

Shared

Open

The Data Spectrum helps you understand the language of data.

theodi.org/data-spectrum
Geoengineering

The Many Stakeholders and Effects of Stratospheric Aerosol Injection

- Can be afforded by an affluent country or billionaire
- Implementation by militaries without public participation is cause for concern
- Precipitation may cause droughts and flooding
- May help prevent creation of climate refugees
- Ozone depletion leads to disruption of carbon and food cycles
- Reduces incentive to reduce fossil fuel use

Blue Donaton, Julie Romano
INTRODUCTION

The 2018 Intergovernmental Panel on Climate Change (IPCC) report listed a 1.5 °C average global temperature rise above pre-industrial levels as the accepted maximum before major damage occurs to natural systems and human society. To avoid global disaster, humans must either focus on mitigation by greatly reducing greenhouse gas emissions or adapt to the new conditions the continuously warming climate will produce. While the current climate change debate typically falls along those lines, there exists a third option. Geoengineering, also referred to as climate engineering, is defined as the practice of deliberately altering Earth’s climate system on a large-scale in order to mitigate the adverse effects of climate change, namely average global temperature rise. Geoengineering technologies have untapped potential, but the costs and benefits need to be weighed carefully to avoid unwanted outcomes. This brief will focus on Stratospheric Aerosol Injection, a particular form of geoengineering that has the potential to completely negate global temperature rise, but at a potentially high cost to society.

Stratospheric Aerosol Injection (SAI) is the injection of reflective sulfur dioxide aerosols into the atmosphere in order to lower global average temperatures. The inspiration behind this technology is typically attributed to the 1991 eruption of Mount Pinatubo where large amounts of sulfur dioxide were released into the atmosphere and perturbed the Earth’s radiative balance resulting in a global average temperature decrease of 0.4-0.5 K. Aerosols are only temporary and in this case had precipitated out of the atmosphere by 1993.

Currently, SAI is almost entirely a theoretical solution due to technological limitations and potential dangers. In order to be implemented, SAI requires specialized aircrafts that can both handle heavy loads and fly ~20km in altitude, higher than any current cargo planes. If released at the high altitudes of the stratosphere, the sulfur vapor will cool and mix with the ambient air forming a plume which brings about the intended cooling effect. Given the complexity of atmospheric science and how many unknowns still exist within the field, it is likely impossible to physically isolate SAI research, leaving a high risk for unintended consequences.

Despite being largely theoretical, SAI differs from other geoengineering technologies due to the subjectively low difficulty needed to implement it. Cost estimates vary, but average estimates predict the need of 1.5 million tons of aerosol to offset current temperature rise for the next 15 years. At US$1500 per ton, estimates total roughly US$2 billion. Studies have shown that in order to implement a large scale SAI project, meaning enough SAI to reduce and maintain temperatures at pre-industrial levels, a fleet of 1000 aircrafts would be needed. In terms of governance, in 2010 the UN Convention on Biodiversity, which included 193 members, agreed to ban geoengineering, with further regulations implemented in various countries; however, the U.S. did not sign the agreement and current governance does little to enforce the existing ban, leaving SAI open for possibilities.

The current argument around SAI is whether it should be considered a necessity or a distraction and a danger. The necessity argument largely assumes that humans will rise above the 1.5 °C limit and face the dangers of catastrophic climate change if SAI is not used, a theory supported by studies showing societies are not reducing their carbon footprints fast enough to avoid temperature rises. The distraction argument, rather, cites how human behavior still needs to be changed as carbon pollution will only continue to grow if polluters believe it is no longer important to reduce their impacts on the environment. For some, the known and unknown dangers are enough to eliminate SAI as a consideration.

ENVIRONMENTAL COSTS AND BENEFITS

SAI implementation could lead to a global drop in temperature, reversing the negative impacts of warming on the environment. Currently, estimates suggest roughly one in six species could face extinction from climate change related effects following the thousands that already have. While not the only symptom of climate change, heat can be a major problem for many species. For example, changes in temperature have resulted in life cycle changes to many plant species across the world, creating an asynchronous cycle between plants and their pollinators. This has led to reductions in key species, such as bumblebees. Temperature reductions would also prevent loss of habitat from sea level rise, which has already removed over 20 square miles of land from the Atlantic coast alone.

Another concern about SAI is its ability to deplete Earth’s ozone layer. Ozone depletion leads to increased UV radiation which has been tied to decreased reproductive fitness in phytoplankton and changes to terrestrial plant development which can have cascading effects on ecosystem health. The first negative impacts of ozone loss were observed in the mid to late 20th century from the use of chlorofluorocarbons, which have since been regulated.
Yet, SAI may require a reversion of the ozone. While numbers vary depending on implementation strategy used, studies support that 1-13% of Earth’s atmospheric ozone may be depleted if SAI is implemented. Even 1% represents a significant loss, especially if it becomes centralized in just a few locations.

SAI models have also predicted implementation of this technology will likely lead to global changes in precipitation patterns. While the exact areas affected depend on how the technology is implemented, it appears that monsoon affected areas are the most likely to be affected. In some areas like Asia and Africa, SAI is predicted to cause decreased precipitation while in others it is predicted to cause increased precipitation. Environmental impacts due to precipitation include increased flooding and mudslides or increased droughts and soil erosion.

While SAI can be used to contrast temperature rise, it does not prevent other impacts of greenhouse pollution, such as ocean acidification. Roughly 26% of carbon dioxide in the atmosphere enters the oceans, turning it into carbonic acid and lowering the water’s pH. This has caused a variety of effects such as large die off’s of plankton and coral bleaching. While it may not be as impactful, sulfur dioxide creates sulfuric acid when mixed with water and thus could have a similar acidifying effect on the environment, albeit to a lesser scale. If further ocean acidification is to be avoided, greenhouse reductions are needed which may negate the need for SAI.

SAI is also predicted to need a long term commitment, with models indicating the ceased use of the technology will cause a rebound effect, leading to rapid climate warming. With continued pollution, more sulfur dioxide will be needed, raising costs of SAI and the power of the rebound effect. This could also exacerbate SAI’s other effects. Some experts have stated that there is the potential to mitigate the majority of these negative impacts of SAI through proper implementation; however, there is nothing proving these claims. The number of unknowns are too great for implementers to determine how these impacts can be correctly mitigated, if at all.

SOCIAL COSTS AND BENEFITS

SAI has the potential to prevent major loss to society by limiting coastal erosion. Globally, coastal areas tend to have the highest rates of economic activity, with 40% of people living near coasts. If climate change continues at its current pace, it is estimated that the number of people currently at risk due to sea level rise will increase from 270 million to 450 million by 2100. Areas such as Manhattan will be at high risk to storm surges, with some areas permanently underwater, damaging lives and global economic activity. In India, there have been an average of 1,551 flood related deaths from precipitation changes per year from 1978 to 2006. SAI has the potential to prevent these refugees and other damages, but also may create new ones from its own climatic impacts.

SAI also has the potential to increase the gaps in social equality between developed and undeveloped countries, usually split between the global north and south. This potential is mainly linked to uneven changes in precipitation and temperature change SAI is likely to cause, with the worst impacts predicted to affect monsoon areas like Southeast Asia. Changes in water availability in these regions is driven by monsoon patterns and the alteration in precipitation patterns have already caused significant damage to infrastructure, crops, property, and loss of human life. These areas may see less cooling while countries such as the U.S. will likely have much more mild climate impacts from SAI, making the risk of implementation much lower.

Some experts also mentioned the relevance of who does and does not currently play a role in SAI debates. Fossil fuel industries have been credited as some of the strongest influencers calling for implementation. These industries can derive great benefits if SAI were implemented as it would allow them to continue to cause carbon pollution and thus profit. Even experts in support of implementing SAI expressed concerns that it would allow for continued environmental pollution rather than making changes they see as necessary for truly improving the climate. Meanwhile, heavily affected populations like the indigenous Aymara people of Bolivia, have been left out of the discussion thus far. The Aymara have a largely agricultural economy and already face high poverty rates due to wide scale droughts from climate change, with a potential for increased droughts from SAI. Despite Bolivia producing 0.04% of the world’s carbon emissions they are still heavily affected by the world’s climate alterations making them important stakeholder in the debate. The social impacts of SAI may be mitigated through proper implementation, but this mitigation is not guaranteed, requiring strict governance if the SAI implementation were to move forward.

The Five Oxford Principles

1. Geoengineering regulated as a public good
2. Public participation in geoengineering decision making
3. Disclosure of geoengineering research and open publication of results
4. Independent assessment of impacts
5. Governance before deployment

Given the number of unknowns with SAI and the variety of ways it can be employed it can be difficult to judge this technology using traditional risk assessment tools. As an alternative this study proposes using the “Oxford Principles.” These principles are a set of 5 proposed guiding principles for governance of geoengineering technologies. In order to be considered for implementation, a proposed
geoengineering technology needs to be able to be governed in all five ways. This brief will discuss whether or not SAI can meet all these principles and what that entails for its governance and its potential for implementation.

**Principle #1: Geoengineering to be regulated as a public good**
A public good is commonly defined as a commodity or service that one can use without reducing its availability to others and of which no one is deprived. Under this definition, SAI can be considered a public good as it is available to everyone and no one’s use diminishes anyone else’s. However, a public good does not have to be beneficial to those it effects. SAI can be considered a public good even if its implementation does end up leading to environmental degradation and/or increased social inequalities.

**Principle #2: Public participation in geoengineering decision making**
Given SAI’s potential the lives of everyone on earth as well as the environment, everyone can be considered a primary stakeholder and thus important to involve in the decision making process. It is unclear though what constitutes public participation. One method commonly used to evaluate public participation is known as the trinity of voices. This method looks at the public’s access to decision-making spaces, its standing in decision-making processes, and its influence over the decisions being made, even when it does not ultimately change the outcome. While often advocated for, public participation in SAI can be argued to go against its own founding principle if defined too loosely.

Experts generally believe that wide public participation is unlikely to happen in geoengineering. The majority of discussions thus far, even on an international scale, such as at the IPCC, have taken place primarily within the developed world and have mostly involved scientists and decision makers. Primary stakeholders such as indigenous groups in the Arctic who are heavily affected by climate change, have been almost entirely left out of the discussion. Experts also note that the implementation of SAI could only occur through the direct involvement of powerful governments and military bodies which are generally places characterized by low levels of public participation.

**Principle #3: Disclosure of geoengineering research and open publication of results**
In discussing this principle it is important to take into account both the present and potential future of SAI. In the current situation, this principle has already been upheld. The majority of research articles on SAI are open publications, accessible to those with internet access. Additionally this study found no examples where research on SAI was not disclosed to the public; however, some experts are speculative about unknown work being performed in certain countries. While SAI development has remained open to the public sphere, there is no guarantee this openness would continue in the future.

**Principle #4: Independent assessment of impacts**
Principle #4 requires SAI research to be evaluated by an unassociated third party. It holds individuals accountable by ensuring rogue work cannot be completed and the repercussions of illegal action be enforced. Similar to principle #2, the standards are ambiguous, needing specificity on what qualifies as an independent assessor. This principle has the potential to be achieved, but requires a stricter definition and global consensus.

**Principle #5: Governance before deployment**
As mentioned previously, SAI has great potential for large scale impacts on a global scale across multiple dimensions, but also has many known unknowns. This principle takes into account both factors, requiring strong government oversight to ensure SAI is used as intended its impacts can be properly studied in the real world. Some experts stressed that deployment does not equate to global deployment. However, other experts did stress the need to heed caution as any real world testing will have the same effects as global deployment albeit on a smaller scale. Similar to other principles, ambiguity leaves room for missteps, but with more clarity could be achieved.

**RECOMMENDATIONS AND FINAL THOUGHTS**
SAI’s negative impacts might be mitigable and its ability to meet each of the oxford principles plausible; however, as one study points out, plausible is an insufficient basis to make decisions, especially when there are global stakes. One principle was especially unlikely to be achieved, suggesting further reason to cast doubt on SAI. Despite the principles phrasing, geoengineering still requires some form of global governance. SAI offers a number of environmental and social drawbacks, meaning it could potentially create more inequalities than it solves. With expert feedback, potential impacts, and a review of the five oxford principles in place, this brief offers a few recommendations, with the key recommendation being for a moratorium on SAI testing and implementation for the foreseeable future.

A moratorium would allow for continued SAI research through modelling, but would need to ban real world testing and implementation for countries. A penalty for action against the moratorium would need to be in place to ensure compliance. It is also recommended this moratorium stay in place until there is significant support from participating stakeholder groups for the need to implement SAI. This allows for SAI to be utilized should climate change be deemed too significant for mitigation and adaptation to handle. This decision must include major stakeholders not currently well included, such as southern nations and indigenous peoples.
Avoiding a binding legal ban leaves room for negotiation in terms of SAI’s necessity. While there have been efforts to mitigate climate change, new carbon-polluting infrastructure is still being built suggesting change may not come fast enough. Presently, there is great concern global average temperatures will surpass the recommended 1.5 °C increase, at which point geoengineering may be needed. Though SAI has the potential to cause a number of problems, they are arguably less impactful than the problems caused by the catastrophic levels of climate change that the IPCC describes. However, there is time to reduce emissions accordingly without the use of SAI.

Before ending, this brief finds it important to admit its limitations. Similar to other entities, this brief does not include discussion from indigenous peoples, like the Aymara people, or experts in the global south. The need for such voices became apparent and was pointed out, but only near the end of our interviewing and research process.


ANNEX I. CONSULTED EXPERTS

<table>
<thead>
<tr>
<th>Name</th>
<th>Institution</th>
<th>Position</th>
<th>Interview Date</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Siegel, Donald</td>
<td>Syracuse University</td>
<td>Research Professor, Earth Sciences and Professor Emeritus</td>
<td>20/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Sugiyama, Masahiro</td>
<td>The University of Tokyo</td>
<td>Associate Professor</td>
<td>14/11/2019</td>
<td>Japan</td>
</tr>
<tr>
<td>Rasch, Phillip</td>
<td>Pacific Northwest National Laboratories</td>
<td>Chief Scientist for Climate Science</td>
<td>18/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Ribeiro, Silvia</td>
<td>ETC Group</td>
<td>Latin America Director for ETC</td>
<td>25/11/2019</td>
<td>Mexico</td>
</tr>
<tr>
<td>Fuhr, Lili</td>
<td>Heinrich Böll Foundation</td>
<td>Author, Head of International Environmental Policy Division</td>
<td>22/11/2019</td>
<td>Germany</td>
</tr>
<tr>
<td>Stenchikov, Georgiy L.</td>
<td>King Abdullah University</td>
<td>Professor</td>
<td>25/11/2019</td>
<td>Saudi Arabia</td>
</tr>
<tr>
<td>MacMartin, Douglas</td>
<td>Cornell University</td>
<td>Senior Research Associate</td>
<td>25/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Lenferna, Georges Alexandre</td>
<td>University of Washington</td>
<td>Professor Climate Justice Campaigner</td>
<td>21/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Wagner, Gernot</td>
<td>New York University</td>
<td>Author, Associate Professor</td>
<td>19/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Kashwan, Prakash</td>
<td>University of Connecticut</td>
<td>Associate Professor</td>
<td>18/11/2019</td>
<td>United States of America</td>
</tr>
<tr>
<td>Jeffrey, Pierce</td>
<td>Colorado State University</td>
<td>Associate Professor</td>
<td>17/11/2019</td>
<td>United States of America</td>
</tr>
</tbody>
</table>

ANNEX II. METHODS

Expert Interviews
Experts were chosen from a variety of backgrounds and countries and were set up with semi-structured interviews. Ultimately, the majority of responders ended up being academics, such as professors, from developed countries. Interviews notes were transcribed, but the sessions were not otherwise recorded.