Master's Thesis – master Sustainable Business and Innovation

Gene-editing crops to benefit smallholder farmers in developing countries:

Realised potential or empty claims of inclusive innovation?

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Abstract
This research studies the potential of gene-edited crops to deliver inclusive innovations: innovations that benefit marginalised groups. New gene-editing technologies such as CRISPR/Cas9 promise to contribute to overcoming challenges of food insecurity and poverty by improving crops. Though claims are made for this, these claims have not been tested. Studies on social implications of gene-edited crops are lacking. This research fills this literature gap by studying the research question: ***How inclusive are gene-editing research projects of crops for smallholder farmers in developing countries?*** For answering this, the inclusive innovation ladder (IIL) is enriched with distributive justice theory, into a comprehensive framework for analysing inclusion. The research is conducted by 23 semi-structured interviews studying 18 research projects that use gene-editing to improve crops with the aim to benefit smallholder farmers (SHFs). The results find that gene-editing realised the promise to include SHFs only to a certain extent. The projects only limitedly fulfil inclusion in all steps of the ladder and for the three distributive justice approaches. Furthermore, this research finds that gene-editing projects take different approaches towards inclusion. It identifies two models, which are metaphorically named Spacecraft and Helicopter models. Spacecrafts develop their crops far away from the ground and do not land to interact with SHFs before their crop is finished. Their inclusion on the higher steps of the IIL is very limited, as well as their equalizing and fairness aspects. Helicopters on the contrary land in developing countries to speak with SHFs, to ensure their crops meet the needs of the SHFs. Their inclusion on step 4-6 of the IIL is more profound and they have more inclusion measures of equalizing and fairness approaches. Despite being more inclusive, also for Helicopter projects inclusion could be improved on various aspects. This research gives concrete recommendations for how inclusion this could be done. The theoretical framework proved to be useful in identifying the limitations of inclusion, therefore it could be used in future research on inclusivity of innovations, in the agricultural sector and beyond.

List of abbreviations

ASEAN	Association of Southeast Asian Nations
CGIAR	Consultative Group on International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CRISPR	Clustered regularly interspaced short palindromic repeats
FAO	Food and Agriculture Organisation
GE	Gene-editing/genome-editing
GM	Genetic Modification
GMO	Genetically Modified Organism
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIL	Inclusive Innovation Ladder
IRRI	International Rice Research Institute
IPR	Intellectual Property Rights
PPB	Participatory Plant Breeding
PPP	Public Private Partnership
SHF	Smallholder farmer

Table of contents

1. Introduction

In 2019, an estimated over 650 million people were undernourished, in Africa a shocking 19% of the population (FAO, 2020c). In the near future, population growth and climate change will pose even increasing challenges to food security, especially for the poor in developing countries (Schmidhuber & Tubiello, 2007). A proposed solution for overcoming food security and poverty is to alter genes of agricultural crops through genetic modification (GM) (Godfray et al., 2010; Ruane & Sonnino, 2011). GM can improve crops on valuable traits such as disease resistance and salt or drought tolerance (Godfray et al., 2010). However, there has been intense debate over the desirability and regulation of GM (Biddle, 2017). The discussion on Genetically Modified Organisms (GMOs) started since the first GM seeds were approved in the mid 1990s (Motta, 2014). This debate has not been settled up to this day (Biddle, 2017).

Although the GM debate focuses on environmental and health-safety risks, also socio-economic and ethical issues have been raised (Daño, 2007). Scholars argue that GMOs have caused inequality and excluded small and poor farmers in developing countries (Gonzalez, 2006). This can be explained by the fact that a handful large private companies conducted majority of GM research (Bonny, 2014; Fischer et al., 2015). Consequently, GM research was mainly driven by profit, leading to a concentration of R&D on the most widely cultivated crop varieties (Bonny, 2014). From 1996 to 2017, 99% of global GMO seed sales was from only four crops: maize, soybean, cotton and canola (ISAAA, 2017). Due to the R&D bias towards large capital intensive farms, varieties suitable for marginal environments in developing countries have not been developed (Fischer et al., 2015). Only one percent of GM research targets poor and small farmers (Gonzalez, 2006). In this context, the claim that GMOs reduce inequality and provide benefits for developing countries has been questioned (Biddle, 2017; Fischer et al., 2015). Furthermore, poor farmers in developing countries face challenges in adopting GMOs. Gonzalez (2006) argues that most small and poor farmers do not have the cash or credit to buy seeds of GM crops and therefore GMOs disproportionally benefit wealthy farmers. A literature review finds that small and poor farmers in developing countries have limited access to GM crops (Fischer et al., 2015). This all indicates that the about 500 million small and poor farmer households in developing countries (FAO, 2015) face challenges in benefitting from GM technology.

The exclusion of small and poor farmers in developing countries is promised to change, however, with the emergence of new gene-editing technologies such as CRISPR/Cas9. Improving agricultural crops by altering their genes using biotechnology tools becomes cheaper, faster, easier and more precise with these new technologies (Gao, 2018). The discoverers of CRISPR/Cas9 even won a Nobel Prize on the revolutionizing impact this tool has, amongst others on improving crops (NobelPrize, 2020). As new gene-editing technologies require less resources than GM, improving crops with biotechnology is not anymore solely possible for large private companies with high R&D budgets (Bonny, 2014; Gao, 2018). Academia and companies of all sizes have started using gene-editing tools (Gao, 2018). Also those varieties that were previously neglected for GM (often called orphan crops) can now more easily be modified using the latest gene-editing technologies (Gao, 2018; Zaidi et al., 2019). Using gene-editing to improve orphan crops that are predominantly grown by small and poor farmers in developing countries on their tolerance to for example biotic and abiotic stresses can contribute to food security (Haque et al., 2018).

The characteristics of new gene-editing techniques thus hold potential for improving crops to benefit developing countries. However, we should not take these promises for granted. Also for GM, similar promises were made (Buechle, 2001), but as elaborated upon before, debated whether they are realised. Scholars have argued that because of the ambiguity and irreversibility of gene-editing technologies as CRISPR/Cas9, it is important to carefully consider the application of such technologies (Bartkowski, 2019; Jasanoff et al., 2015). Though gene-editing of crops promises to create benefits for the poor, we should be cautious whether this claim will actually be realised.

It is remarkable that there are no studies on whether gene-edited crops indeed will benefit the poor in developing countries and thereby could lower inequality and poverty. This is remarkable because of the numerous claims about the potential benefits of gene-editing technologies for developing countries (e.g. Gates, 2018; Ma et al., 2018; Zaidi et al., 2019). So far, discussion around gene-edited crops mainly focus on health and environmental safety (Bechtold, 2018). An analysis of socio-economic implications of using CRISPR/Cas9 for editing crops is lacking (Bartkowski et al., 2018). An ethical review addresses that the impact of gene-edited plants on resource poor communities is "*potentially ambiguous*", (Nuffield Council on Bioethics, 2016, p.70), but does not further elaborate upon how these communities will (not) benefit from gene-edited crops. The few studies on inequality in gene-editing that do exist, focus on the equal representation of stakeholders in democratic processes (e.g. Jasanoff et al. , 2015) but do not discuss the potential of gene-editing to reduce inequality and poverty in developing countries. This literature gap is addressed in this research.

This research studies the potential of gene-editing to reduce inequality and benefit the poor by studying inclusion. For this, inclusive innovation theory is used. Inclusive innovation theory describes innovations that include marginalised groups in the process and outcomes of the innovation (Heeks et al., 2013). Inclusive innovations aim to "*create opportunities and enhance the well-being for disenfranchised members of society*" (George et al., 2012, p.663). Contrary to mainstream innovation, that proved to be unsuccessful in benefitting the poor (Cozzens & Sutz, 2014) and led to increased inequality (Schillo & Robinson, 2017), inclusive innovation is specifically aimed at benefitting marginalised groups such as the poor (Fisher, 2017). Inclusive innovation theory has been taken up by a growing number of academic and international organisations such as the World Bank and the OECD (Heeks et al., 2013). To capture the different ways of how marginalised groups can be included in innovation, Heeks et al. (2013) developed the inclusive innovation ladder (IIL) framework. It defines inclusion on six steps of a ladder: intention, consumption, impact, process, structure and post-structure (Heeks et al., 2013). This research uses the IIL to analyse inclusion of marginalised groups of gene-edited crops.

For this I choose to study the marginalised group of smallholder farmers (SHFs) in developing countries. The common definition of SHF is that they grow their crops on less than 2 hectares of land (Anthony & Ferroni, 2012). I focus on SHFs in developing countries for two reasons. Firstly, because they are an important marginalised group. About 65% of the 3 billion developing world's rural people live in about 500 million SHF households (FAO, 2015). They are generally poor and face food security issues (FAO, 2015). For example, 83% of Bolivian SHFs live below the national poverty threshold, and in Ethiopia SHF households on average only earn 0.9 USD per person per day (FAO, 2015). Secondly, because SHFs are promised to benefit from gene-editing, but face difficulties and thus require specific measures. SHFs face difficulties in the uptake of agricultural technologies, because of poorly developed infrastructure and institutions (Mwangi & Kariuki, 2015). Specifically, weak seed systems cause that SHFs have low accessibility to seeds of improved varieties (McGuire & Sperling, 2016). Besides, limited financial resources and access to financial credit also cause constraints (Gonzalez, 2006). For gene-editing technologies to create benefits for SHFs, these challenges need to be overcome. For these reasons, this research focuses on SHFs for studying inclusive innovation in gene-editing by answering the following research question:

How inclusive are gene-editing research projects of crops for smallholder farmers in developing countries?

The aim of this research is to explore the potential of gene-editing to deliver inclusive innovations: innovations that can benefit the poor and reduce inequality. The research question is answered by analysing gene-editing research projects. Gene-edited crops are in an early stage of development with only a handful of products on the market (Molteni, 2019), thus studying products is not feasible. Research projects provide the earliest indication of (a lack of) inclusion. Research projects that aim to bring benefits to SHFs are selected for this, for example a project on cassava brown streak resistance (Gomez et al., 2019; Mollins, 2017) and disease resistant cocoa (Penn State, n.d.). Though the projects all focus on crops for SHFs in developing countries, the location of the project teams is beyond developing countries. The project teams are based both in developing and developed countries. By interviewing 24 members of 18 research projects, this research aims to generate understanding of their inclusion of SHFs in developing countries.

When studying inclusion, it is important to take into account that stakeholders have different perspectives on whether and how inclusion is achieved (Harsh et al., 2018; Levidow & Papaioannou, 2018). The GM debate exemplifies this. For example for step 3 of the IIL: impact, there is disagreement on whether GMOs created positive impact for developing countries (Beumer & Swart, forthcoming). To incorporate different perspectives, this research uses distributive justice theory on normative viewpoints. I hypothesize that what is considered as ‘inclusive’ depends on the different normative viewpoints that stakeholders have. An innovation could be judged as inclusive from the perspective of one normative viewpoint, but not from another. Cozzens (2010) explains this in three distributive justice approaches for benefitting the least advantaged members of society; 1) pro-poor, 2) fairness and 3) equalizing. This theory is combined with the IIL into a theoretical framework useful for analysing and classifying the inclusion measures of the research projects. Thereby the different perspectives on inclusion are incorporated which helps to identify what inclusion measures are (not) taken and how inclusion could be achieved.

This research adds to the academic field in two ways. Firstly, previous studies on the non-technological aspects of gene-editing in agriculture have mostly focused on health-safety and environmental issues (e.g. Araki et al., 2014; Kleter et al., 2019; Steinbrecher, 2015; Wolt, 2017). This research, instead, aims to shed light on the socio-ethical aspect of inclusion of marginalised groups. Secondly, I will enrich inclusive innovation theory with insights from work on distributive justice. Whereas some scholars have previously combined these two, (e.g. Harsh et al., 2018; Levidow & Papaioannou, 2018), I will combine insights from both fields in a comprehensive framework for all steps of the IIL. This is relevant as the acknowledgement that innovation can be judged as inclusive from the perspective of one normative viewpoint, but not from another, is not addressed in the IIL. Academics could use the developed theoretical framework for analysing inclusivity of other innovations, in the agricultural sector as well as other industries.

This research is relevant for society, as new gene-editing technologies are expected to quickly and extensively impact the agriculture industry (Bartkowski et al., 2018; Gao, 2018). This fast development indicates the necessity to identify broader implications and uncover the potential to address the needs of marginalised groups. Gene-editing can have positive effects on these marginalised groups. However, historical evidence shows that previous agricultural innovations failed to benefit the poor, which even led to growing inequality between poor and rich farmers. For example, innovations in the green revolution actually caused losses of income of farmers without access to the technology as productivity gains by other farmers lowered the market prices of crops (Evenson & Gollin, 2003; Gonzalez, 2006). In India, this even worsened the situation of the poorest farmers and led to increased inequality among farm incomes (Saini, 1976). This example shows that if only rich, large scale farmers benefit from gene-editing technology, inequality and poverty could increase. This demonstrates the necessity to consider whether SHFs in developing countries are included in gene-editing crop research. The marginalised group of SHFs in developing countries is especially relevant as the 500 million SHF households make up a large majority of the poor and face increasing agricultural challenges (FAO, 2019). Therefore, addressing this group is useful to contribute to finding solutions to reduce poverty and inequality.

2. Theoretical framework

2.1 Previous crop improvements and SHFs

If we are interested in inclusive gene-editing innovations for SHFs in developing countries, it is important to consider previous crop improvement efforts. The historical context in which gene-editing innovations are situated can help understand how gene-editing can be different in being inclusive towards SHFs. This section discusses the extensive literature available on previous crop improvements.

Starting, we will look at the context of agricultural research. Where R&D activities take place can give insights in what barriers arise for SHFs to be able to benefit from this R&D. From reviewing literature, I found that the agricultural R&D context is characterised by a concentration in 1) developed countries and 2) private organisations.

Firstly, R&D activities are geographically concentrated in developed countries. In 2011, high-income countries invested over 11 times as much per capita in agricultural R&D compared to low-income countries (Pardey, Chan-Kang, et al., 2016). This gap was wider than in 1980 (Pardey, Chan-Kang, et al., 2016). Furthermore, there is reduced donor support and lack of prioritization by developing countries' governments for agricultural R&D (Beintema & Stads, 2010). There is thus limited, and reducing, investment in agricultural R&D in developing countries. Limited investment makes it unlikely that developing countries will develop improved varieties for their SHFs.

Secondly, R&D activities are increasingly concentrated in the private sector. Historically, agricultural R&D was dominated by public actors such as universities and government agencies (Pardey, Chan-King, et al., 2016). Currently agricultural R&D is increasingly executed by private companies, in high-income countries the private sector is good for 50% of the investments (Pardey, Chan-King, et al., 2016). In 2011, for every dollar of private agricultural R&D spent in high- income countries, only 0.8 dollar cents was spent in low-income countries (Pardey, Chan-Kang, et al., 2016). This shows that the private sector R&D investment is concentrated in developed countries. Private R&D investment is mostly directed towards a few major crops grown in developed countries (Fuglie, 2016). Globally, less than 1% of all private R&D investment is on crops especially relevant for SHFs, such as cassava, banana and coffee (Fuglie, 2016). Additionally, the little private agricultural R&D in developing countries, has focused on crops and traits relevant for local industrialised farmers, not for SHFs (Naseem et al., 2010). This indicates that the increasing R&D investment by private actors is not expected to create varieties for SHFs in developing countries.

From this context, several constraining factors for SHFs are evident. These factors limit the benefits brought to SHFs by previous crop improvements, such as those associated with the 'green revolution' and the 'gene revolution'. It is evident that those revolutions created a numerous amount of improved crop varieties (Parayil, 2003). The extent to which crop improvement benefitted SHFs was however hampered by three main factors: suitability, affordability and accessibility.

Firstly, lack of suitability limited SHFs in developing countries to benefit from crop improvements. Suitability means that crops are developed that meet the needs of SHFs as well as their environments. There are large differences per crop on how much research is conducted and to what extent advancements have been achieved. Hurley et al. (2016) claims, based on 500 evaluation studies, that 37% of all agricultural R&D investment between 1990 and 2015 was on 3 crops only: maize, rice and wheat, and that almost 50% of R&D was invested in cereals only. Cereals are also grown by SHFs and SHFs in Asia and Latin America experienced large yield gains in cereal crops (Davies, 2003). However, cereal improvement only benefitted SHFs if the improved crops were suitable for SHFs' environments. Agricultural conditions in developing regions can be very different to conditions elsewhere (Wu & Butz, 2004). Many high yield varieties in the green revolution were not suitable for African conditions such as their weather pattern (Pinstrup-Andersen & Schioler, 2001). In this line Wu & Butz (2004) explains that because local conditions were ignored in development, improved crops did not perform well in SHF fields. Lack of suitability of improved crops for SHFs' environment can thus restrain SHFs to benefit from these crops.

Besides, suitability of the crop type caused exclusion of SHFs. Along with cereal crops, many SHFs rely on so-called "orphan crops" (Tadele, 2019). Orphan crops remain underinvested in agricultural R&D. Tadele (2019) exemplifies this by the case orphan crop teff in Ethiopia. In Ethiopia there are 40% more teff farmers than wheat farmers. However up to 2015, almost 5 times less teff than wheat varieties were introduced. This exemplifies the limited crop improvements in orphan crops. A notable exception are the efforts by several CGIAR (Consultative Group on International Agricultural Research) centres. In the green revolution, CGIAR centres released improved orphan varieties such as sorghum, millet, cowpea and cassava (Wu & Butz, 2004). However, these improvements have not led to as significant yield gains as in rice and wheat (Wu & Butz, 2004). As less research is conducted on orphan crops, there is less technical know-how available. This makes it challenging for researchers to improve orphan crops (Tadele, 2019). There is thus limited focus in R&D activities on orphan crops, despite their suitability for SHFs.

Secondly, affordability: when SHFs cannot afford improved varieties, they simply cannot benefit from them. High prices (Jack, 2013; Langyintuo, 2020), limited access to credit (Alwang et al., 2019), lack of cash resources (Langyintuo, 2020) and lack of financial services (Fan et al., 2013) caused exclusion of SHFs from crop improvements. Wu & Butz (2004) explain that in the green revolution SHFs in Asia and Latin America could benefit from relatively expensive improved varieties because of subsidies and low-interest loan systems. Absence of this contributed to unaffordability for African SHFs (Wu & Butz, 2004). Especially female farmers are found constrained to access markets and finance to adopt new agricultural technologies (FAO, 2011), and profited less from improved varieties than male farmers (Pingali, 2012). Affordable prices and financial services are thus key for SHFs to benefit from improved varieties.

Thirdly, inaccessibility created exclusion of SHFs. Accessibility are all factors, other than financial, that determine the ability of SHFs have access to the improved variety. This entails the infrastructure for disseminating the crop to SHFs. In the green revolution, a supportive local infrastructure proved imperative in creating desired effects of improved varieties. A developed local infrastructure in Asia and Latin America contributed to the green revolution taking off in these regions, and not in Africa where such infrastructure was absent (Wu & Butz, 2004). A literature review by Jack (2013) identifies that an inadequate infrastructure such as missing supply chains and unreliable supply or inputs, caused limited access for SHFs. Poor infrastructure for seed dissemination slowed the adoption of improved varieties (Anthony & Ferroni, 2012). Poor infrastructure thus caused that improved varieties were not accessible for SHFs, leading to exclusion of SHFs of benefitting from those crops.

Suitability, affordability and accessibility thus created barriers for SHFs to benefit from crop improvements in the past. Gene-editing needs to overcome these barriers to ensure benefits for SHFs. For SHFs to benefit from improved varieties becomes even more important in the near future, as several additional challenges are expected. Firstly, climate change will harm the agricultural sector drastically and developing countries are especially vulnerable (Williams et al., 2018). Predicted weather extremes are likely to threaten SHFs production and thereby food security and livelihoods (Serdeczny et al., 2017). Additionally, climate change correlates with new crop diseases and pests (Lybbert & Sumner, 2012). Secondly, the prospected population growth will increase pressure on food security, and agricultural productivity growth is not keeping pace with the population increase (Toenniessen et al., 2008). Thirdly, there is increasing pressure on available arable land, such as competition for land for food or biofuel crops (Tomei & Helliwell, 2016), as well as the increasing transnational land acquisitions in developing countries by foreign actors (Dell'Angelo et al., 2017). These challenges show that there is increasing importance for SHFs to benefit from improved varieties.

2.2 Gene-editing

Gene-editing technologies promise to contribute to overcoming the (increasing) challenges SHFs face. Gene-editing is cheaper, faster and easier compared to previous technologies such as GM, which gives a wider range of actor access to the technology (Gao, 2018). To understand gene-editing, we first look at previous crop improvement methods. In Figure 1 this is visualised. With cross breeding, two varieties are crossed and backcrossed subsequently which, after 8-10 years, can lead to a plant with desired genes, the elite variety (Chen et al., 2019). Transgenic breeding arose as an alternative to cross breeding. Transgenic breeding is done by using genetic modification (GM) technology (Halford & Shewry, 2000). Scientist used GM to generate desired traits by bringing other genes in the genomes of crops. Besides transgenic breeding; bringing in genes from another species, GM technology can also be used for cisgenic breeding; bringing in genes from the same species (Schouten et al., 2006). Improving a crop using GM takes relatively long (8-12 years) and comes with high regulatory costs and numerous public concerns (Chen et al., 2019). A quicker and more precise alternative to cross breeding and GM that emerged in the past decade is gene-editing (also called genome-editing) (Gaj et al., 2013).

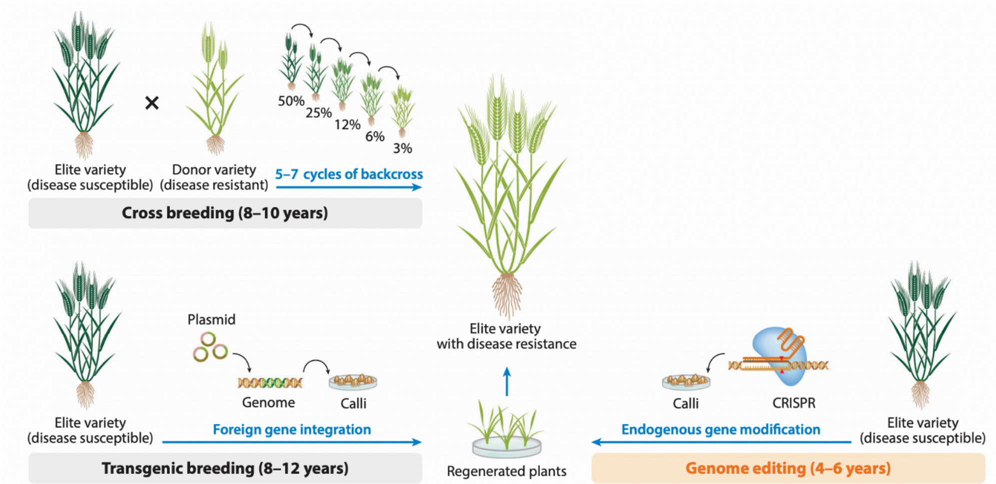

Figure 1: Methods for improving crops (adapted from Chen et al., 2019)

Gene-editing is more precise in altering an organism's genes, as it targets specific chromosomes (Chen et al., 2019). With GM it is not possible to control where and with what frequency gene alternations occur, whereas with gene-editing alterations can be precisely controlled (Enriquez, 2016). New gene-editing technologies as ZFN, TALEN and CRISPR/Cas9 make promises of transforming science (Gaj et al., 2013). Especially CRISPR/Cas9 is popular and seen as "revolutionary" and "ground-breaking", as it is more precise and less expensive than ZFN and TALEN (Schultz-Bergin, 2018). CRISPR/Cas9 is an abbreviation of Clustered Regularly Interspaced Short Palindromic Repeat (CRISPR): the unique DNA sequences found in genomes of bacteria and archaea, and the associated protein Cas9 (Ishino et al., 2018). The protein Cas9 can be seen a molecular scissor that cuts DNA (Jiang et al., 2013). Cas9 uses guide-RNA to lead it to the target site for cutting (Arora & Narula, 2017). Hereby it can substitute a DNA sequence with a desired one or disable whole genes by cutting them out or knocking-out their functions (Montenegro, 2016). The popularity of CRISPR/Cas9 is evident by the number of publications in plant research, where CRISPR/Cas9 easily outpaces ZFN and TALEN (Jaganathan et al., 2018). Figure 2 shows the rapid increase of CRISPR/Cas9 publications.

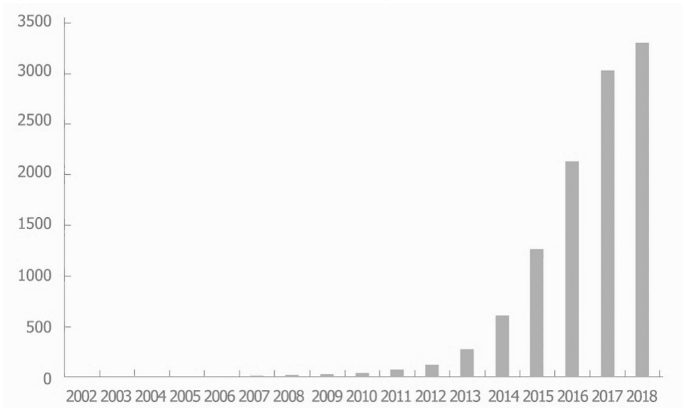

Figure 2: Number of CRISPR/Cas9 publications per year (Limanskiy et al., 2019)

Based on the technical aspects, gene-editing in general, and CRISPR/Cas9 in particular, thus looks promising and is very popular. However, regarding the social aspects, much less is known. There are several literature reviews on crop gene-editing's technical potential, applications and challenges (e.g. Chen et al., 2019; Jaganathan et al., 2018; Zhang et al., 2019). But for the social aspects of crop gene-editing, such reviews are not existing. For human gene-editing, there is quite some social literature (Schultz-Bergin, 2018). There is also some literature on inclusive democratic processes (e.g. Bartkowski, 2019; Jasanoff et al., 2015) and ethical issues of animal welfare (Schultz-Bergin, 2018). However, specifically for gene-editing of crops, non-technical literature remains mostly limited to regulation of gene-edited crops (e.g. Ishii, 2018; Schmidt et al., 2020; Waltz, 2016).

There are a few exceptions that give some insights in the social implications of crop gene-editing. One study found that majority of biotechnology experts agreed that crop gene-editing poses no significant risks to the economy or society (Lassoued et al., 2019). Other scholars found that gene-editing of wheat creates benefits for all actors along the value chain in Germany (Maaß et al., 2019). None of these studies though focus on social implications for developing countries specific. On that, no work has been conducted.

Several authors claim that gene-editing can bring benefits for developing countries (e.g. Gates, 2018; Ma et al., 2018; Zaidi et al., 2019). For example, Gates (2018) argues that gene-editing methods such as CRISPR/Cas9 "*could help end extreme poverty by enabling millions of farmers in the developing world to grow crops and raise livestock that are more productive, more nutritious, and hardier.*" In 2020 the discoverers of CRISPR/Cas9 won a Nobel Prize (NobelPrize, 2020), indicating that it's revolutionary nature is recognised beyond the biotechnology field. It is remarkable that there are no studies that show how and whether the often claimed potential of gene-editing benefitting the poor in developing countries is realised. This research addresses this literature gap using inclusive innovation theory.

2.3 Inclusive innovation

To understand inclusive innovation, it is important to know how it differs from mainstream innovation. The phenomenon "innovation" in recent years became increasingly adopted in academia, business and politics (Fagerberg & Verspagen, 2018). Innovation is seen as the key driver of economic growth (Kalkanci et al., 2019). However, besides this positive association, it also became evident that innovation created negative outcomes in the form of social and economic inequalities (Biddle, 2017; Heeks et al., 2014). In developing countries, economic growth proved not to be associated with improving the socio-economic conditions of the poor (Chataway et al., 2014). For example between 1990 and 2008, the sub-Saharan African economy doubled, while the number of people living below the poverty line of 1,25 USD a day increased by 59% (Chataway et al., 2014). This exemplifies that economic growth, driven by innovation, does not necessarily create benefits for the poor. The type of innovation that improves the welfare of middle- and high income consumers, but not of marginalised groups, is called mainstream innovation (Heeks et al., 2014). On the contrary, "inclusive innovation" is specifically aimed at benefitting marginalised groups, and has the potential to address social exclusions (Fisher, 2017). Inclusive innovation literature combines innovation with social exclusion, poverty and inequality (Onsongo et al., 2017).

The literature field of inclusive innovation started with appropriate technology literature (Chataway et al., 2013). This was triggered by the economics book Small is Beautiful (1973) of E.F. Schumacher, arguing against large production systems and focusing on empowering people (Schumacher, 1973). Benefits for marginalised groups can be created by appropriate technologies that are simple, often locally manufactured and labour-intensive, using a bottom-up approach (Lissenden et al., 2015). From this literature stream, the grassroot innovations movement was founded (Chataway et al., 2013). Grassroots innovation is another attempt to realising benefits for marginalised groups with innovation. The grassroot innovation movement emphasises being inclusive towards knowledge, processes and outcomes of local communities in a bottom-up way. (Smith et al., 2014). For this bottom-up approach, grassroot innovation often involves actors as community- and non-profit organisations, driven by addressing social needs (Onsongo et al., 2017).

Besides this locally oriented "innovation from below", benefits for marginalised groups can also be created by "innovation from above" (Chataway et al., 2013). This refers to global, profit focused innovations that target poor consumers This started with the idea that the large population at the bottom of the pyramid (BOP), the poorest on the income scale, hold enormous potential for generating profit (Prahalad, 2009). This is referred to as BOP innovation or pro-poor innovation, which involves large multi/transnational firms driven by profit that sell innovations to the BOP (Onsongo et al., 2017). Related to this, in India the term "frugal innovation" developed (Chataway et al., 2014). Frugal innovation refers to making simpler, less luxurious versions of products, by which they become affordable for less wealthy consumers (Zeschky et al., 2011).

These innovation types all present different attempts of creating benefits for marginalised groups with innovation. These attempts are captured under the term 'inclusive innovation'. This term was first used in 1999 and since then gained interest (Heeks et al., 2013). Foster & Heeks (2015,) define inclusive innovation as: "*the means by which new goods and services are developed for and by marginal groups (the poor, women, the disabled, ethnic minorities, etc)* (p.2)". This definition thus shows that inclusive innovation for example captures grassroot innovation (developed bottom-up *by* marginalised groups), as well as BOP innovation (developed top-down *for* marginalised groups). To provide a more comprehensive framework on inclusive innovation, that includes elements of all different innovation attempts of creating benefits for marginalised groups, Heeks et al. (2013) introduced the inclusive innovation ladder.

2.4 Inclusive innovation ladder

The inclusive innovation ladder (IIL) was developed by Heeks et al. (2013) to capture different views in literature on including marginalised groups in innovation. It consists of six steps that explain different aspects of inclusion, shown in Figure 3. For example, it entails aspects of bottom-up innovation (step 4: including marginalised groups in the process), as well as of top-down innovation (step 1: the innovation is intended for marginalised groups). By this the IIL integrates different views on how benefits for marginalised groups can be created in one framework. This framework works as a ladder, each step higher means deepening or broadening the inclusion of the marginalised group (Heeks et al., 2013). The lower steps are thus rather superficial, and the higher on the ladder, the more profound inclusion is. This is thereby a useful framework to analyse to what extent gene-editing is inclusive. The following explains each step of the ladder, and immediately discusses how this is made operational for studying gene-editing crop projects.

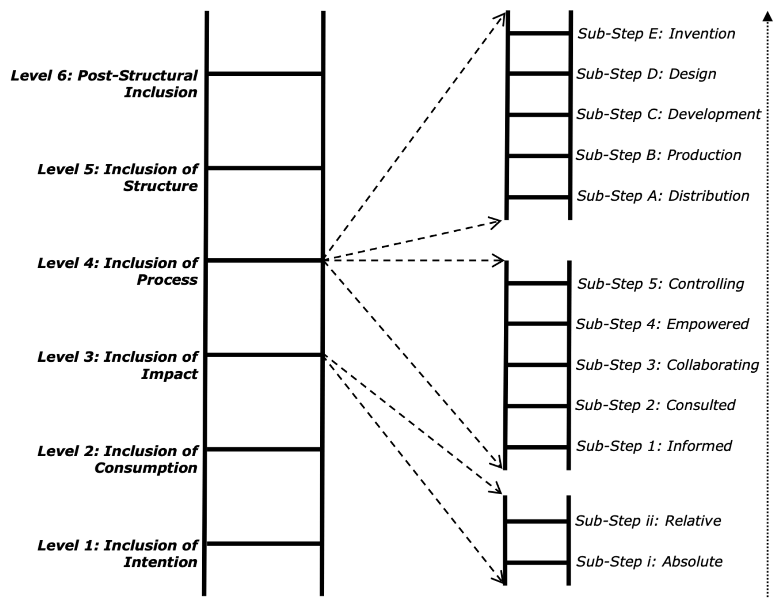

Figure 3: Inclusive Innovation Ladder (Heeks et al., 2013)

Step 1: intention entails the intention to address the wants or needs of the excluded group (Heeks et al., 2013). In this research this means that the project *intends* for the crop to create benefits for SHFs in developing countries. It refers to how they set their intentions; what crops and traits they decide to focus on. However, merely intention does not ensure that those benefits are actually created. For example, the introduction of Bt Cotton in South Africa, aiming to improve the farmers competitive position, is argued to have not achieved this (Witt et al., 2006). On the other hand, sometimes innovations are not intended for a marginalised group, but will be consumed by them (step 2) and possibly create benefits (step 3). Therefore, it is important to look further than intention, for example to the consumption of the innovation.

Inclusion in **step 2: consumption** entails that the innovation is consumed by the excluded group (Heeks et al., 2013). In this research, the consumer of the crop is the SHF in the developing country that is growing the crop. After growing the crop, the SHF (consumer), either sells the harvest or could eat the crop in case of a food crop. As none of the research projects are in the phase where the crop is grown by SHFs, this step refers to the plans of the projects to achieve this. For a SHFs to become a consumer, it is crucial that the projects specifically target SHFs as their consumers and have measures in place to overcome accessibility and affordability challenges explained in section 2.1. When the crop is consumed by SHFs, the question is what impact is created. This is the next step of the ladder.

Step 3 Impact entails that the innovation has positive impact on the livelihoods of the excluded group. There are different ways in which impact can be conceptualised; from quantitative economic aspects of productivity and welfare, to more qualitative aspects of well-being and capabilities, and from absolute (marginalised group benefits) to relative impact (marginalised group benefits more than other groups; leading to lower inequality) (Heeks et al., 2013). The crops of the projects are not yet grown by the SHFs; therefore, the intended or expected impact is most relevant to study in this research.

For inclusion in **step 4:** the excluded group is involved in the **process** (or most likely; members of this group). For this step, Heeks et al. (2013) identified two sub ladders, one with forms and the other with moments of inclusion. The form of inclusion can range from being informed, to collaborating, to eventually controlling. The moment of inclusion can range from the very beginning of an innovation (invention) to the end (distribution). In this research, this step analyses how SHFs are involved in the research project's processes. A closely related concept of involving farmers in crop improvement, is Participatory Plant Breeding (PPB) (Morris & Bellon, 2004). Figure 4 shows how PPB (right) differs from traditional methods of breeding (left). In the latter, all the decisions are taken by the breeders, while in PPB decisions are taken jointly and the process is decentralised. Similar to the sub-ladders of the IIL, PPB literature also elaborates upon the moment and form of involvement. Both IIL and PPB literature explain that for optimal inclusion in process, research projects should be controlled by SHFs from the very beginning of the projects.

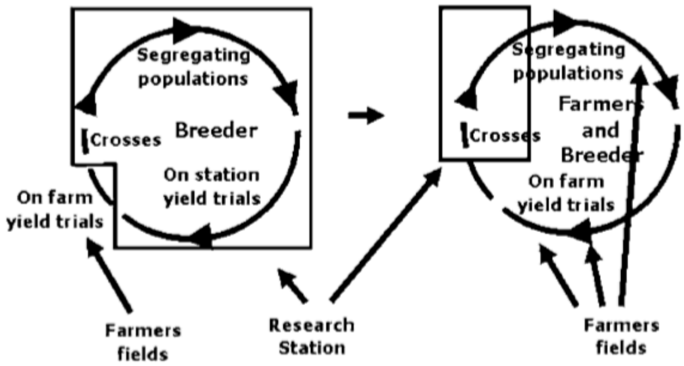

Figure 4: Participation in plant breeding's traditional system (left) and PPB system (right) (Ceccarelli & Grando, 2007)

Inclusion in **Step 5: Structure** means that the structure of an innovation system, consisting of institutions, organisations and relations (Heeks et al., 2013) is supportive towards innovations for the excluded group. This is thus broader than previous steps, as structure goes beyond the gene-edited crop itself. The research projects can take measures to contribute to building a supportive structure for inclusive innovation. Heeks et al. (2013) explains that the innovation system structure has several aspects:

- Legal/policy infrastructure: policies and regulations necessary to support inclusive innovation (Heeks et al., 2013). For example, this includes science policies for innovation, and regulations for human and environmental risk management. In this research regulation is especially relevant, as gene-editing regulation is currently fragmented and differs per (developing) country (Schmidt et al., 2020). Projects can for example lobby for beneficial regulations so developing countries will allow gene-edited crops, which makes consumption (step 2) possible for SHFs.
- Institutional infrastructure: collaborative structures and organisations that support inclusive innovation (Heeks et al., 2013). For example, this could be an institution that helps researchers with identifying needs of marginalised groups (step 1) or supports them with their dissemination (step 2). Projects could for example establish a new institution or collaboration for such support for gene-editing research to benefit SHFs.
- Human infrastructure: skills and knowledge for inclusive innovation (Heeks et al., 2013). For example, this includes training and knowledge transfer to other researchers which builds human capacity (Hall, 2005). In this research it refers to researchers that have the skills and knowledge to use gene-editing for improving SHF relevant crops. A human infrastructure that is capable of using gene-editing technology is a prerequisite for more and better research of this technology. Although gene-editing is said to be more accessible to execute for all types of actors compared to GMOs (Gao, 2018), it remains a technological lab tool that requires specific skills.
- Financial infrastructure: accessible capital for inclusive innovation (Heeks et al., 2013). This refers to whether there is capital available to fund gene-editing crop R&D, it does not entail funding for affordability of the crop itself. The latter is covered in step 2: consumption. Projects could try to increase the amount of capital for crop R&D, for example by lobbying for this at funding organisations. More financial support for gene-editing projects could lead to more projects that work on crops for SHFs.

- Technological infrastructure: diffusion and availability of technology (Heeks et al., 2013). For example, this includes technology transfer to other researchers in conferences. Projects can share their knowledge on gene-editing technologies with other researchers. Furthermore, it also includes the Intellectual Property Rights (IPR) system, which entails a dilemma for inclusiveness. If IPRs are absent and technology is shared, also called “open innovation”, more actors can use the technology, leading to that more innovations can be developed that could possibly create benefits for SHFs (Harsh et al., 2018). However, contrastingly, IPR is needed to create incentives to actually bring the technology to the poor (Harsh et al., 2018). A middle way for projects could be to patent their technology, but freely license this for inclusive applications.
- Public support: the drivers or barriers to inclusive innovation caused by the public (Heeks et al., 2013). For example, this includes public opinion on a technology. Public opinion and controversy has appeared to be a very important barrier to development of technology, such as the lack of consumer acceptance of GM crops (Lucht, 2015). Research projects can aim for public support by informing the public about gene-editing technology.

Finally, the last step of the IIL entails **post-structural** inclusion **(step 6)**. It entails the frames of knowledge and discourse of key actors in the innovation system that need to be inclusive itself for an innovation to be truly inclusive (Heeks et al., 2013). This means that the innovation changed assumptions about science, knowledge and the wider system towards including of marginalised groups in these frames (Woodson & Williams, 2020). Williams & Woodson (2019) explain that post-structural inclusion is amorphous and very difficult to achieve for a single innovation but could be achieved by a series of innovations. For example, a series of innovations on household appliances changed the role of women in the household (Williams & Woodson, 2019). First measures of post-structural inclusion can be found in analysing knowledge and language (Heeks et al., 2013), such as the inclusion of indigenous knowledge into scientific research (Harsh et al., 2018). In this research, the inclusion of SHF knowledge in the projects will therefore be analysed. Also, whether the projects communicate in local language(s) of SHFs can indicate post-structural inclusion. Lastly, when inclusion of the excluded is placed central in an organisation and their goals, this can indicate post-structural inclusion (Onsongo et al., 2017). Post-structural inclusion is the highest step of the IIL.

The above six steps explain different ways in which inclusion can be achieved, whereby inclusion is more profound each step higher. The authors explain that this ladder has an accumulative nature; for each step higher, inclusion in the step below needs to be achieved first (Heeks et al., 2013). However, they also indicate that the higher up the ladder, there is less empirical evidence that supports this claim (Heeks et al., 2013). It is thus unsure whether this accumulative nature is also the case for the highest steps of the ladder. This is important to know for giving recommendations for inclusion. If the accumulative nature is not found, projects could for example be recommended to firstly ensure inclusion in step 6, before working on step 4. This research will analyse all steps of the IIL and thereby review whether the accumulative nature is indeed confirmed in general, and in higher steps of the ladder in specific. Next to using the IIL for analysing inclusion, I will thereby contribute to the IIL by testing its accumulative nature.

2.5 Distributive justice

Though the IIL is useful for analysing inclusion of innovations, it also has shortcomings. Harsh et al. (2018) and Levidow & Papaioannou (2018) point out that it does not address that what is seen as inclusive depends on the perspective or assumptions of stakeholders. An innovation could namely be judged as inclusive from one perspective, but not from the other(s). Harsh et al. (2018) explain that there are different perspectives on inclusion in different steps of the IIL. An example is step 5, structure. From one perspective this step is inclusive when it creates jobs for women, from another perspective when it creates jobs for the poor (Harsh et al., 2018). Levidow & Papaioannou (2018) explain that from one perspective an innovation is inclusive when training of low-income groups will grant them access to the innovation, whereas another perspective will only consider training as inclusive when there is equal knowledge-exchange between the producers and consumers. These examples show that inclusion does not mean the same for everyone.

For biotechnology specifically, literature also shows that views on inclusion differ. Regarding impact (step 3), actors disagree on whether GMOs have a positive impact on African farmers (Osiemo, 2018). Proponents argue that increased productivity and yield benefitted the farmers, whereas sceptics considered broader contexts of institutional conditions, and do not agree on created benefits (Beumer & Swart, forthcoming). This shows that actors can disagree on whether inclusion in steps of the ladder is actually achieved.

Based on the above, I hypothesize that what is considered as 'inclusive' depends on the different normative viewpoints that stakeholders have. An innovation could namely be judged as inclusive from one normative viewpoint, but as not-inclusive from another. What is seen as inclusive depends on the underlying perspective of stakeholders; their normative viewpoints (Levidow & Papaioannou, 2018). I want to contribute to the IIL literature by combining it with theory on normative viewpoints. Distributive justice theories describe the different normative viewpoints stakeholders can have.

Distributive justice theory describes what should be seen as fair or just in distributing benefits and wealth (McDermott et al., 2013). Issues of distributive justice have up to now largely been ignored in innovation science (Smallman & Beumer, submitted.). A notable exception is the work of Suzan Cozzens and colleagues, who used theories of distributive justice to analyse innovation and innovation policies (e.g. Cozzens et al., 2006). These studies draw on different distributive justice theories in deriving to three approaches for reaching equity and assessing distributive impacts of emerging technologies. It is appropriate to use this theory as gene-editing is an emerging technology (Huang et al., 2016). The three approaches for distributive justice of Cozzens are (based on: Cozzens, 2008; Cozzens, 2010; Cozzens et al., 2006):

1) Pro-poor: does the innovation focus on creating benefits for the poor? The goal from a pro-poor viewpoint is to reduce poverty or alleviate its conditions. This can be done by improving the lives of poor households or lifting those households out of poverty.

2) Fairness: does the innovation reduce horizontal inequalities by creating benefits for disadvantaged groups? The goal from a fairness viewpoint is to eliminate the horizontal inequalities of society. Horizontal inequalities are inequalities based on culturally defined aspects, such as gender, ethnicity or religion.

3) Equalizing: does the innovation reduce vertical inequalities by changing socio-economic structures? The goal from an equalizing viewpoint is to eliminate vertical inequalities of society by changing socio-economic structures, for example a structural change that leads to growing of the middle of income distribution. Vertical inequalities are inequalities of differences in income, wage or wealth.

Innovations can be seen as inclusive from distributive justice approaches, such as a fairness approach for poor communities, but the approaches can also conflict (Cozzens, 2008). For example, according to a fairness approach, an innovation is inclusive when it reduces horizontal inequalities, despite whether vertical inequalities are increased (equalizing). Similarly, an innovation is inclusive according to a pro-poor viewpoint if it benefits the poor, regardless whether vertical (equalizing) or horizontal (fairness) inequalities increase. An innovation could thus be judged as inclusive from the perspective of one normative viewpoint, but not from the other(s).

To incorporate normative viewpoints in this research, the measures taken by the research projects will, besides classified along the lines of the IIL, also be classified along the three distributive justice approaches. I combined these two theories in a theoretical model, shown in Figure 5. Take as an example that research projects creates jobs. In this light, Harsh et al. (2018) argues that creation of jobs for disadvantaged groups such as women relates to fairness approach, whereas creating good jobs for poor communities would be an equalizing approach (Harsh et al., 2018). One could also think of in what processes (step 4) marginalised groups should be involved. Following a pro-poor approach, marginalised groups should merely be involved in design of the innovation, to ensure the technology benefits poor, whereas in an equalizing approach they should also be involved in deciding over ownership issues, to change socio-economic structures and lower vertical inequalities. Different distributive justice approaches thereby lead to different measures to achieve inclusion.

Distributive theory thereby helps to identify the measures that research projects can take for inclusion. With the theoretical framework, I can analyse according to what distributive justice approaches the projects are (not) inclusive. Adding distributive justice theory helps to identify and classify the inclusion strategies that the projects follow. The methodology for analysing the research projects using this theoretical framework is explained in the next section.

	Pro-poor	Fairness	Equalizing
6: Post-structural	Measure X	Measure X	Measure X
5: Structure	Measure X	Measure X	Measure X
4: Process	Measure X	Measure X	Measure X
3: Impact	Measure X	Measure X	Measure X
2: Consumption	Measure X	Measure X	Measure X
1: Intention	Measure X	Measure X	Measure X

Figure 5: Theoretical framework

3. Methodology

3.1 Research design

To answer the research question "*How inclusive are gene-editing research projects of crops for smallholder farmers in developing countries?*", this research used a deductive, qualitative research design of an embedded case-study. A deductive approach was chosen because there is a rich amount of literature on inclusive innovation available. Qualitative research is suitable as it is useful for exploring unanticipated phenomena (Maxwell, 1996) and inclusivity in gene-editing is an unexplored topic. Qualitative research is also appropriate as there were only few research projects using gene-editing, as it is still in an early stage of technological development. Besides, this research aimed to understand perspectives on inclusiveness, and a qualitative approach is suitable for researching perspectives of participants (Hammarberg et al., 2016). As this research was designed to generate deep understanding of a phenomena by studying multiple research projects, it can be described as an embedded case study (Scholz & Tietje, 2002; Yin, 2003).

The embedded case study was executed by analysing research projects that use gene-editing technologies to modify crops for SHFs in developing countries. I analysed the inclusion measures that these projects (will) take using the theoretical framework of the inclusive innovation ladder (IIL) and distributive justice approaches, summarised in Figure 6. The theory of the IIL was developed to analyse innovations that are already on the market. However, I used it in an earlier phase of the innovation process, namely when products are still in the development phase. This means that for some steps I could not analyse what already happened. For example, for step 3: impact, conventional IIL analyses would measure the impact an innovation had. As the crops are not yet grown by SHFs, I instead analysed the impact that the crop is prospected/intended to have. This is the best proxy there is for inclusion this early in the innovation's phase of development. This research thus analysed the (plans of) inclusion of research projects using the theoretical framework.

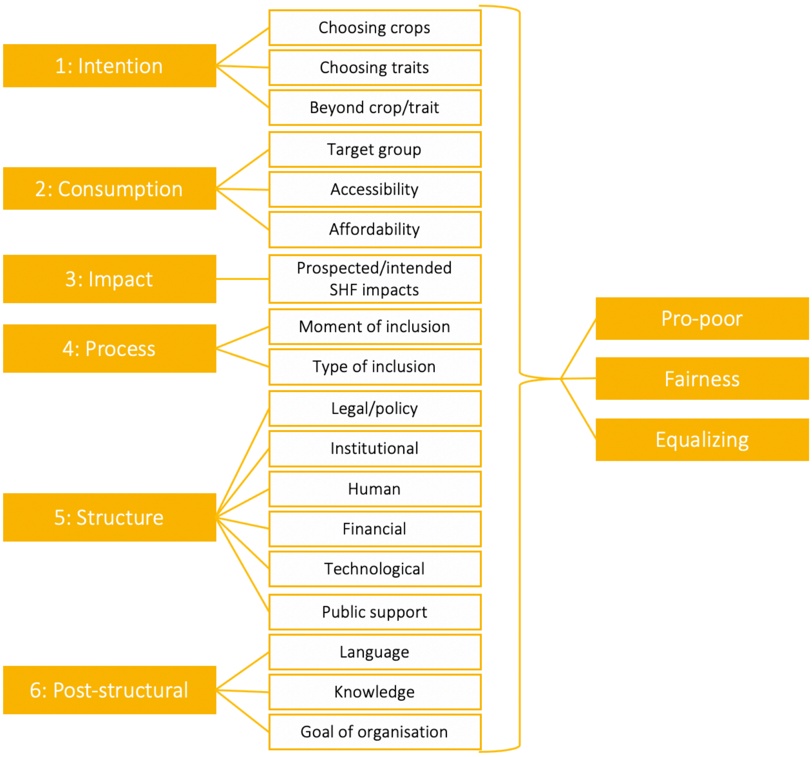

Figure 6: Operationalisation of the theoretical framework

This research thus took gene-editing research projects as the unit of analysis. This was chosen as there are only a handful gene-edited crops on the market (Molteni, 2019) of which none in developing countries. Analysing research projects thereby can give the first insight in whether inclusion is (not) achieved. Projects are an increasing economically important way of organising and coordinating the control and production of goods and services (Steen et al., 2018). Projects are different to other ways of organizing, such as companies. Projects are temporary organisations with a start and end (even though they often do not finish in time or seem to end at all) (Steen et al., 2018). Temporary organisations are defined as: "*a set of diversely skilled people working together on a complex task over a limited period of time*."(Goodman & Goodman, 1976, p. 494). It is important to realise that projects should not be regarded in isolation: "no project is an island" (Steen et al., 2018). Projects operate within a wider system and are interlinked with other projects as well as institutions. This was in this research included amongst others by analysing step 5 of the IIL: the structure around an innovation. Besides, chapter 4 discusses the context in which the projects are situated: the research landscape of gene-editing. This shows how the wider system was incorporated while having research projects as the unit of analysis.

3.2 Data collection

For data collection, I selected research projects that use gene-editing to modify crops to benefit SHFs in developing countries. These projects had to match two criteria; 1) they work on crops relevant for SHFs, and 2) they specifically intend to benefit SHFs. These two criteria are further explained below.

Criteria 1) Relevant crops: The projects needed to work on improving crops that are relevant for SHFs. Projects that focus on SHF relevant crops are most likely to include SHFs in the benefits created. The crops that were found relevant for SHFs are listed in Appendix II. This list is drafted based on several sources. The list entails crops that are a) important to end hunger, b) orphan crops and c) cash crops.

a. The "Crops to end Hunger" of the CGIAR institute, an international research network for food security. 20 crops that according to CGIAR are most important to improve food security in developing countries, through increasing productivity and income of SHFs (CGIAR, 2018).

The CGIAR list entails the most important crops that are cultivated by SHFs widely around the world. However, also less widely cultivated varieties are relevant for SHFs. Orphan crops play an important role in the economy of developing countries, and for SHFs specifically (Tadele, 2019).

b. Orphan crops. Crops in the list of Orphan Crops for the developing world, a review combining academic sources (Tadele, 2019) and crops in the list of Orphan Crops of Africa (African Orphan Crops Consortium, n.d.).

Besides food crops, also cash crops such as cotton and cocoa are relevant for SHFs. They are an important part of income of for example African SHFs (Diao & Hazell, 2005).

c. Cash crops. Crops covered in the programme "Sustainable Smallholder Agribusiness" (SSAB, n.d.). This programme trained over 1.3 million SHFs in Africa.

Criteria 2) Specific intentions: The project needed to state that they develop the gene-edited crop for SHFs in developing countries[1]. This is necessary to only include projects that specifically intend to benefit SHFs. For example, maize is relevant crop for SHFs; it is one of the “crops to end hunger” (CGIAR, 2018). However maize is also largely grown in the developed world (FAO, 2020b). The theory explained that without a specific intention of benefitting SHFs, it is unlikely that an improved maize variety will be suitable, accessible and affordable for SHFs. The specific intention to benefit SHFs is thereby the second criteria that the projects needed to adhere to.

Projects that met both criteria were selected for this research, because these projects have the potential to benefit SHFs in developing countries (criteria 1) and specifically intend to do so (criteria 2). Though the projects all had to focus on creating improved crops for SHFs in developing countries, there was no criteria for the location of the project’s teams. The scope of the location of projects was beyond developing countries. The research groups could be based at organisations located both in developing and developed countries.

I used four methods to find the research projects. Firstly, academic publications were explored. This was a useful method as with new scientific method as gene-editing, it is likely that researchers publish their results. For this, Google Scholar and Scopus were searched for academic publications, using the search terms of Table 1. For some crops the number of publications found was too numerous to go through one by one. For example, searching for CRISPR and maize yielded over 14.000 results. Therefore, those crop names were combined with additional terms to filter the results on projects with the intention to develop the crop for SHFs in developing countries (see Table 1). Secondly, to search for news articles and websites, a Google and Google news search was conducted. For this, the search terms in Table 1 were used as well. This was relevant as scientific publications can be rather specific and technology focussed and might not state the wider intention of benefitting SHFs. This was though more likely to be covered in news articles or on websites.

Table 1: Search terms

<table>
<tr><td rowspan="2">Gene edit* OR genome edit* OR genome engine* OR CRISPR OR TALEN</td><td rowspan="2">AND</td><td>Agricultur* OR farm* OR cultivat* OR crop OR plana</td><td>AND</td><td>“Developing countr*” OR “developing nation*” OR “underdeveloped countr*” OR “underdeveloped nation*” OR “low-income countr*” OR poor OR poverty OR smallholder OR small-scale” OR “family farm*” OR “resource deprived” OR marginalised OR excluded</td><td>OR</td><td>Orphan OR neglected OR underutilised OR niche OR indigenous</td></tr>
<tr><td>Names of selected crops in Latin and English (See Appendix II)</td><td>AND (if more than 25 hits)</td><td>“Developing countr*” OR “developing nation*” OR “underdeveloped countr*” OR “underdeveloped nation*” OR “low-income countr*” OR poor OR poverty OR smallholder OR small-scale” OR “family farm*” OR “resource deprived” OR marginalised OR excluded</td><td colspan="2"></td></tr>
</table>

[1] Or similar wording, e.g. small-scale farmer, marginalised farmer, family farmer, the name of a developing country or region, for development, for the poor. Appendix I explains of how and why the term developing countries is used.

Thirdly, nine review articles on crop gene-editing were inquired (Arora & Narula, 2017; Chen et al., 2019; Han & Kim, 2019; Haque et al., 2018; Jaganathan et al., 2018; Jiang et al., 2013; Ricroch et al., 2017; Schaeffer & Nakata, 2015). These articles provided an overview of the gene-editing or CRISPR/Cas research on crops. This included review articles that specifically focused on the use of gene-editing or CRISPR/Cas in tropical crops, which increased the probability to identify projects focused on SHFs. Fourthly, the snowballing method was used. Snowballing means that initial interviewees are used to get contact with others (Bryman, 2016). Interviewees were asked if they knew other gene-editing projects that aim to benefit SHFs. With this also projects without an academic publication, website or news article were included.

Using above methods, in total 30 research projects were found. An interview with all 30 projects was requested. Interviewing was chosen as it is a relevant method for acquiring in-depth information (Bryman, 2016). In total, 23 interviews with 24 interviewees were conducted of 18 different projects. Mostly, leaders of the projects were interviewed. I chose to preferably interview leaders as they have influence over decision making on inclusivity and have the best overview of the project's activities and structure. This follows the key informant technique: informants should have a role necessary for gaining the information looked for (Marshall, 1996). In two cases, the leader of the project was not available and instead another team member was interviewed. If a research project was a partnership, all organisations involved were contacted for interviews. This followed the embedded case study method where different interest groups are seen as different units of the studied case (Scholz & Tietje, 2002). In projects for international development, different partners can have different agendas and prioritization of goals (Pilbeam, 2013). Therefore, it is important to interview not only the leader, but also partners, as they might have different views on inclusion. Consequently, the 24 interviewees were not limitedly project leaders, but also other team members and partners.

The interviews were conducted following a semi-structured interviewing method. This method gives the interviewer guidance to address necessary topics, while it allows flexibility (Bryman, 2016). This was suitable for this research as gene-editing for SHFs is an underexplored topic. By flexibility in the interview, also unexpected topics that came up could be asked further questions about, allowing for more complete results. The interview guide was drafted based on the theoretical framework (see Figure 6) and is added in Appendix III. The interview guide included questions about the different steps of the IIL and the different distributive justice approaches. These questions were based on the operationalisation of both theories discussed in detail in the theory section. The interviews took between 28 mins and 1 hour and 28 mins. Interviews were held via Skype or Zoom, as the geographic spread of interviewees made face-to-face interviewing unfeasible. All interviews were recorded, for which consent was ensured by asking this prior to the interview. Consent for using the interviewee's- and organisation's name was ensured in the same way. An overview of the interviews is shown in Table 2.

Table 2: Overview interviews (names removed for anonymisation)

Interview #	Name of interviewee	Organisation	Type of actor	Duration
1			Public	0:57h
2			PPP Public	1:03h
3			Public	1:12h
4			Public	1:01h
5			Start-up	0:28h
6			Public	0:47h
7			Public	0:55h
8			Public	0:49h
9			PPP Private	1:07h
10			Public	0:57h
11			Public	0:41h
12			Public	1:02h
13			Public	1:16h
14			PPP Public	1:07h
15			Public	0:49h
16			Public	1:01h
17			PPP Private	0:51h
18			Public	1:01h
19			Public	0:59h
20			Public	0:50h
21			PPP Public	01:01h
22			Start-up	01:23h
23			PPP Private	0:44h

3.3 Data analysis

For analysing the data, the interviews were first transcribed and subsequently coded. Coding is a relevant process for categorising and structuring findings (Bryman, 2016). Coding helped to generate overview from the large quantity of acquired interview data. The program NVivo was used for the coding process. Firstly, statements of interviewees were categorised under the different steps of the IIL. Secondly, these statements of different interviewees under single steps were categorised under different distributive justice theories. Finally, the statements were coded in a more open way, finding differences and similarities in the ways that inclusion in the steps of the ladder and the distributive justice approaches were realised by different projects.

An iterative approach was taken in the coding process. The interviews gave new insights in how measures should be classified, and therefore the coding framework was adapted throughout data analysis. This iterative approach ensured that measures for inclusion were not wrongly classified or excluded. Such an iterative approach is central in the Grounded Theory method, where concepts and categories are developed based on the collected data (Strauss & Corbin, 1994). An example of this is step 1: intention. Various projects also had intentions beyond improving crops on certain traits. This was therefore added in the coding framework. The coding framework thus developed in an iterative way. The final coding framework is added in Appendix IV.

After coding the interviews, the codes were analysed. By this, (lacking) inclusion on steps of the IIL, as well as for the distributive justice approaches became evident. Based on this, patterns were looked for that could categorise the projects based on differences and similarities in their approach to inclusion. This was done to be able to better understand the variation in inclusion among the projects. For example, inclusion patterns based on the type of crop (orphan, staple, cash), the type of project (PPP, public, start-up) and the project's country (developing or developed) were looked for. Also, patterns based on (limited) inclusion on a specific step of the ladder was analysed. This led to the identification of two models that in a different way do (not) include SHFs along the different steps of the IIL, as well as along the different distributive justice approaches. To distinguish the two models, I used metaphors to make the differences clear and easy to understand. The data analysis and two models finally led to the conclusion of how inclusive the gene-editing projects of crops for SHFs in developing countries are.

4. The research landscape of gene-editing

From the theory section (2.1) it is clear that agricultural R&D does not automatically result in varieties that benefit SHFs in developing countries. The question is how gene-editing fares thus far in being more directed towards creating benefits for SHFs. To answer this, this section discusses the general research landscape of gene-editing. This research found only 30 research projects that specifically focus on SHFs, while there are over 2000 publications on crop gene-editing over the past five years alone. This indicates that gene-editing research overall is not strongly focused on SHFs. At first sight, the gene-editing research landscape shows similarities to that of previous agricultural research. The focus is mostly on cereal crops and research is concentrated in developed countries. This suggests that overall gene-editing did not result in dramatic changes in the research landscape towards applications that specifically benefit SHFs.

Gene-editing R&D, to start with, mostly focuses on crops and traits whose relevance for SHFs is not immediately clear. Two review papers on crop gene-editing (Bao et al., 2019; Gupta et al., 2020) for example found that research is mainly conducted on major cereal crops, that are also grown in developed countries. This is shown in figure 7 and 8. 95 of 264 CRISPR applications found by Gupta et al. (2020) focus on major cereal crops. Rice is a frontrunner within cereal crops and constituted 31% of all the CRISPR crop applications found by Bao et al. (2019). Followed by rice are cereal crops wheat and maize. The past shows that a focus on major cereal crops produced both in developed as developing countries will not automatic translate in SHFs benefits, as varieties improved for the developed world are often not suitable for SHFs (Wu & Butz, 2004). Besides a major focus on cereal crops, 19% of CRISPR research focuses on tomato (Bao et al., 2019). Tomatoes are grown by SHFs in developing countries (Masunga, 2014), though also largely produced in the US and Europe (FAO, 2020b).

Distribution of publications based on the type of plant studied.

Groups	Crop	No. of publications[a]
Cereals	Rice	76
	Maize	10
	Wheat	9
	Sorghum	1
	Barley	2
Legumes	Soybean	9
	Medicago	3
Oilseeds	*Brassica*	2
	Linum	1
	Camelina	1
	Potato	5
	Horticultural Crops[b]	37
	Others[c]	115

Based on literature (n=264) collected from Web of Science (Accessed on April 7, 2018).

[a] Some articles describe more than one plant spp.

[b] Includes plants like Tomato, Citrus spp, Grapes, Apple, Cucumber, Banana, etc.

[c] Includes plants like *Arabidopsis* spp, *Nicotiana* spp, Cotton, Papaver, Woody plants, etc.

Figure 7: Review of gene-editing publications per crop (Gupta et al., 2020)

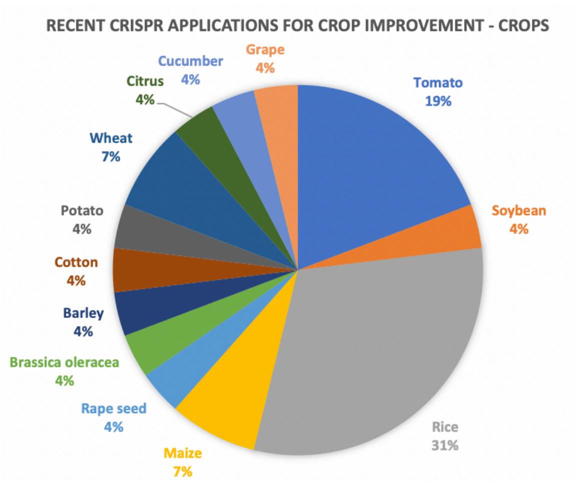

Figure 8: CRISPR applications per crop, drafted from data of (Bao et al., 2019)

To benefit SHF, research on crops relevant for both developed and developing countries needs to specifically focus on SHFs to ensure suitability for them. For example, a focus on useful traits. In Figure 9, Bao et al. (2019) show that 35% of CRISPR research focuses on increasing yield (e.g. grain number, grain size). This can be relevant for SHFs in developing countries, but also for other types of farmers globally. The focus on abiotic- (14%) and biotic (34%) stresses (Bao et al., 2019) could align with the needs of SHFs. These stresses are increasingly important for SHFs in developing countries due to climate change (Newton et al., 2011). However, this is also the case for farmers in developed countries (Newton et al., 2011). It thus seems that majority of gene-editing research is not steered exclusively towards creating SHF benefits.

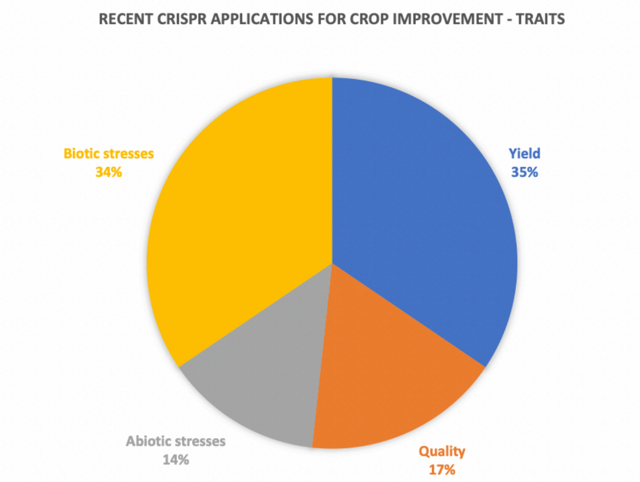

Figure 9: CRISPR application per trait, drafted from Bao et al. (2019)

Though to a lesser extent, also crops especially relevant for SHFs are focused on. Figure 7 and 8 show that next to major cereal crops, gene-editing has been applied to a great diversity of other crops. Gupta et al. (2020) reports that 37 studies focus on various horticultural crops, like banana. In the tropics, bananas are the fourth most important staple crop and majorly grown by SHFs (Swennen et al., 2000). Bao et al. (2019) reports that 4% of CRISPR applications focus on cotton. Cash crops as cotton are grown by SHFs and play major roles in economies of developing countries (Baffes, 2003). Also, one study on the orphan crop sorghum is found (Gupta et al., 2020). Orphan crops as sorghum are grown by SHFs and have potential in providing food security (Mwadalu & Mwangi, 2013). Yet while gene-editing is hence applied to SHF relevant crops as cotton and banana, and orphan crops as sorghum, the focus is on major cereal crops. Overall this suggests that gene-editing focuses on benefits for farmers in developed countries.

Besides concentration on certain crops, gene-editing crop research is concentrated in developed countries. Three overview studies analyse the location of publications or patent filings (Gupta et al., 2020; Martin-Laffon et al., 2019; Ricroch et al., 2017). These studies agree on the three main regions for gene-editing research: US, China and Europe. Of the CRISPR patents for plants, China filed 60.5%, followed by the US (26%) and Europe (8%) (Martin-Laffon et al., 2019). Next to these three main regions, Japan, Canada, Brazil, India and Australia are prominent countries in gene-editing research. According to Gupta et al. (2020), together they make up 22% of the gene-editing patents for crops. In patent filings India ranks 7th, which is especially relevant as in India over 85% of the farmers are smallholders, in total an estimated 126 million (Bisht et al., 2020).

Though concentrated in develop countries, also developing countries conduct gene-editing research. LaManna & Barrangou (2018) visualised the distribution of over 100.000 CRISPR plasmids, an often used tool for gene-editing. Figure 10 shows the absence of CRISPR research in almost all of Africa, whereas in several developing countries in South America, as well as in India and Indonesia some research is conducted. In Indonesia 93% of the farmers are SHFs (FAO, 2018) and as explained India is home to about 126 million SHFs. This show the relevance of gene-editing crop research in these countries. These overviews show that gene-editing research is possible for developing countries as well, although majorly concentrated in developed countries. The latter raises questions over whether gene-editing will focus on applications for SHFs in developing countries. That research is mostly conducted in developed countries, again suggests a focus of gene-editing on (large-scale) farmers in developed countries.

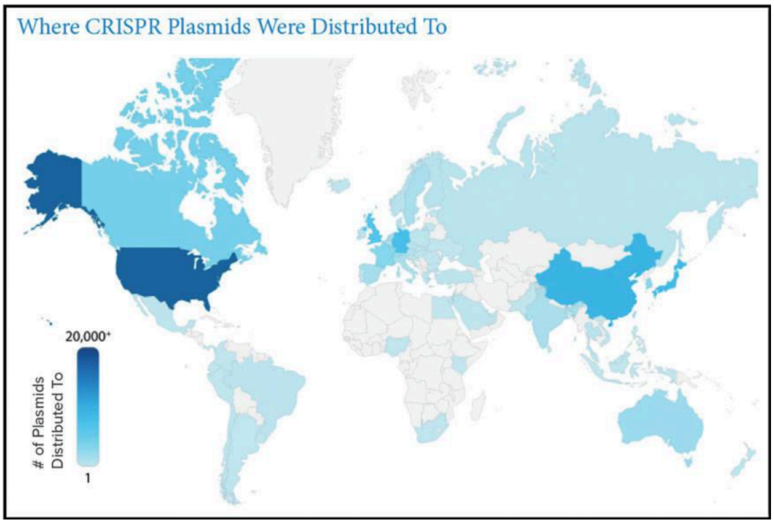

Figure 10: Geographical distribution of CRISPR plasmids (LaManna & Barrangou, 2018)

Summarizing, this overview of gene-editing research shows that research on gene-editing is mainly conducted in developed countries, on crops that are interesting for farmers in those countries. Although this may occasionally benefit SHFs as well, this nevertheless means that issues that are specifically beneficial to the 500 million SHFs worldwide (FAO, 2020a) are not prioritized. We saw this with previous generations of biotechnology: there too promises were made about the benefits of GM for SHFs (Jansen & Gupta, 2009), which in hindsight did not pan out (Adenle, 2011; Fischer et al., 2015). From this overview it seems like gene-editing is faring in the same way.

This is not to say that gene-editing is not used to target SHF in developing countries at all. In fact, I identified 30 projects with the explicit aim to benefit SHFs in developing countries. These projects are the focus of the remainder of this research. Insights in how they attempt to include SHFs can provide valuable lessons for inclusive gene-editing. The next section discusses the projects at a glance, before deep-diving in the inclusion of the projects.

5. Results

5.1 The SHF gene-editing research projects at a glance

This section gives first insights into inclusion of the 30 research projects that were found following the methodology's criteria. These projects focus on a crop relevant for- and have the intention to benefit SHFs in developing countries. An overview of the 18 projects analysed in this research is given in Table 3. Characteristics of both these 18 interviewed projects, and the 12 projects that were not interviewed, are discussed in this section. Analysing these projects at a glance can already give some understanding in the inclusion of SHFs.

The 30 found projects focus on quite a wide range of crops, shown in Figure 11. On the one hand, this includes crops that are also targeted by general gene-editing research. The most researched variety is staple crop rice (34%). This is not surprising considering the prominent role of rice in gene-editing in general, discussed in chapter 4. The projects also focus on banana, sorghum and cotton; which are also targeted in general gene-editing research.

On the other hand, the projects include crops that were not found in the overall gene-editing landscape, and thus otherwise not studied. For example, 3 projects focus on cassava. Cassava is the most important staple crop for millions of people in the tropics and grown mostly by SHFs (Nassar & Ortiz, 2010). That 10% of the projects focus on cassava, can thus partially confirm that gene-editing enables improvements in important SHF crops. This promise is also partially confirmed by the projects tackling cowpea, millet and tef: all orphan crops (Tadele, 2019). As explained in section 2.1, orphan crops have been underrepresented in mainstream agricultural R&D, despite their important for SHFs. Furthermore, SHF relevant cash crops are focused on as well, namely coffee, cocoa and oil palm. Cash crops play an important role in providing income for rural economies (Achterbosch et al., 2014). Overall, these projects indicate that gene-editing indeed can be used to improve crops that were largely ignored by mainstream agricultural R&D and earlier biotechnologies.

Although various crops are targeted with gene-editing, also numerous relevant crops are missing. There is absence of various of crops from the list of 'crops to end hunger' (CGIAR, 2018), such as pigeon pea, lentils, and groundnut. The total list of crops relevant for SHFs (Appendix II) consists of 139 crops. Many orphan crops remain untouched by gene-editing research. The promise of gene-editing to focus on crops relevant for SHFs is thus only partially realised.

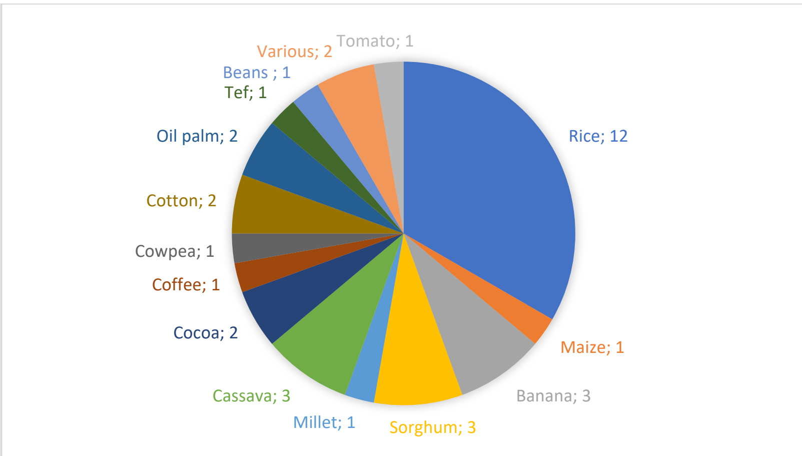

Figure 11: Crops targeted by the 30 found projects

Table 3: Overview of interviewed projects

Crop (alphabetical order)	Crop type	Trait(s)	Country based in	Type
Banana, Coffee, starting with rice	Staple/Cash	Banana panama disease resistance Low caffeine coffee	UK	Start-up
Cacao	Cash	Capacity building Disease resistance	US Ivory coast	Public Public
Cacao, Cassava	Staple/Cash	Disease resistance + quality improvement + lowering metal contamination	US	Public
Cassava	Staple	Brown streak virus resistance	US	Public
Cassava	Staple	Mosaic Gemini virus resistance New starch form	Switzerland	Public
		Capacity building New starch form	Belgium	Public
Cassava	Staple	Lowering cyanide levels	US	Public
Cotton	Cash	Cotton leaf curl resistance	Saudi Arabia	Public
Cotton	Cash	Cotton leaf curl resistance	Pakistan	Public
Maize	Staple	Maize Lethal Necrosis tolerance	Mexico Kenya	PPP Public
Oil palm	Cash	Ganoderma disease resistance Yield	Indonesia	Public
Oil palm	Cash	Ganoderma disease resistance	Indonesia	Public
Rice	Staple	Yield, water & nitrogen efficiency	Australia	Public
Rice	Staple	Cloning hybrid seeds	US	Public
Rice	Staple	Bacterial Blight resistance	Philippines Germany	Public
Rice	Staple	Salt tolerance, floating ocean farms	US	Start-up
Rice (and others)	Staple	Disease resistance Bacterial Blight resistance	US	Public
Tef	Staple	Lodging resistance Grain size	US	PPP Public
Various (Sorghum, Pearl Millet, Cassava, Tef, Maize)	Staple	Various; disease resistance, quality improvement, value adding	US	PPP Private

The 18 interviewed projects focus on various traits that can benefit SHFs. Majority of the projects focus on improving yields, mostly by resistance or tolerance to diseases and pests (12 out of 18). Two projects target other traits that may improve yields: by enlarging grain size and resistance to lodging of teff and by making photosynthesis of rice more efficient.

Projects also focus on other traits than yield. Two projects aim for value adding to the crop; by making cassava starch useful for industry and increasing the quality of cacao. Other projects focus on health factors, namely two projects on lowering disease contributing elements in cassava. One project on rice is making hybrid varieties cloneable. This is relevant for SHFs as hybrid varieties are often not affordable for SHFs because new seeds have to be bought yearly (Vizcayno et al., 2014). Two projects on rice focus on climate change related effects, namely salt tolerance and water efficiency. The above mentioned pest and disease resistant projects are also increasingly relevant in the light of climate change, as they are prospected to occur more often (Lybbert & Sumner, 2012). Besides yield, gene-editing projects thus also focus on several other traits that are (increasingly) relevant for SHFs.

Though relevant traits are focussed on, some traits are notably lacking in Table 3. For example, resistance to climate change related weather extremes, such as drought resistance or tolerance to flooding. This absence is notable because SHFs are especially vulnerable to these effects (Williams et al., 2018). Other traits that one could think of, but are not found, are making crops suitable for degrading soils or making fast maturing crops. Summarizing, the projects mainly concentrate on yield and though other (increasingly) relevant traits are worked on, other important traits seem underrepresented. This could exclude certain SHFs from benefitting from improved varieties.

The actors involved in the research projects are located both in developed and developing countries. The number of interviewees based in developing countries (6 out of 24) is relatively high comparing this to the overall gene-editing landscape. Projects are located in developing countries in Asia and Africa. With the exception of Mexico, no projects were found in Latin-America. The absence of China is particularly remarkable because it's among the three regions with most gene-editing research (see Chapter 4). This absence could be explained by China's market incentives and policy strategies that steer towards large-scale industrial farming, also visible in China's agricultural research priorities (Si et al., 2019). Besides China, the absence of research teams in Japan, Canada, Brazil and India is not in line with the overall gene-editing landscape. This indicates that gene-editing teams in developed countries as Japan and Canada do not use their expertise to create benefit for SHFs in developing countries. Especially the absence of India is surprising. 86% of all farmers in India are SHFs (Bisht et al., 2020) and GM cotton has been grown by Indian farmers for over a decade (Navneet, 2019). It is unexpected that the plenty gene-editing research in India does not seem to focus on SHFs. Overall, a wide geographical spread of the teams is evident, with noteworthy absence of China and India.

The actors involved in the research projects are mostly from public institutions. 13 out of 18 projects constitute of public actors, such as from universities or research institutes. Three projects are part of public private partnerships (PPP) and two are start-ups. This provides an interesting contrast to research with previous biotechnologies that was mostly concentrated in private corporations in developed countries, as we saw before.

Summarizing, some conclusions can be drawn about the potential of these gene-editing projects to deliver inclusive innovations for SHFs in developing countries. This potential can partially be confirmed. Relevant crops and traits are being improved using gene-editing, though absence of other relevant crops and traits contrast this. A relatively large part of the teams is located in developing countries and teams majorly constitute of public institutions, which confirms that gene-editing is accessible for all types of actors. As such, this supports claim that gene-editing can benefit SHFs in developing countries by being affordable and easy to use. These conclusions are however only based on the project's general information. Next, the inclusive innovation ladder is used to shed more light on the way the projects (do not) achieve inclusion.

5.2 Two models

By analysing the results, I found that the projects can be categorised in two models. These two models are distinguished by the absence or presence of inclusion measures on step 4 of the IIL (process) which in turn is found to correlate with differences in other inclusion aspects. As explained in the methodology, inclusion correlated with project's characteristics was also looked for, such as the type of crop, the type of project and the project's country. These characteristics however did not correlate with inclusivity on (multiple) steps of the ladder. Absence or presence of inclusion measures in process (step 4), led to recognizing two models.

On the first three steps of the ladder, all projects show many similarities in the way which inclusion is (not) achieved. However, I found that projects take rather different approaches to inclusion in processes (step 4), and these differences correlate with inclusion measures taken in terms of structure (step 5) and post-structure (step 6). Inclusion in step 4 (process) thereby seemed to be associated with inclusivity higher on the IIL, and furthermore as well with whether all three distributive justice approaches are incorporated.

The two models will from now onwards be described as Spacecraft and Helicopter. Spacecraft refers to that the teams are far from the SHFs; they fly in space. They develop the crops in isolation, without speaking to SHFs, and only land back on earth after they have finished the crops. Helicopters on the contrary fly close to the ground. They make stops in developing countries where they speak with SHFs as well as conduct other activities beyond improving the crop. A further explanation of the metaphors and two models is given in chapter 6. Before this, it is necessary to deep-dive in whether and how inclusion is (not) achieved by the projects in general, and two models in specific. In section 5.3, step 1-3 are explained for all projects, not distinguishing between the models as they largely have the same measures. In section 5.4 and 5.5, step 4-6 of the IIL are discussed for the Spacecraft and Helicopter projects respectively. Figure 12 shows this structure of section 5.3-5.5.

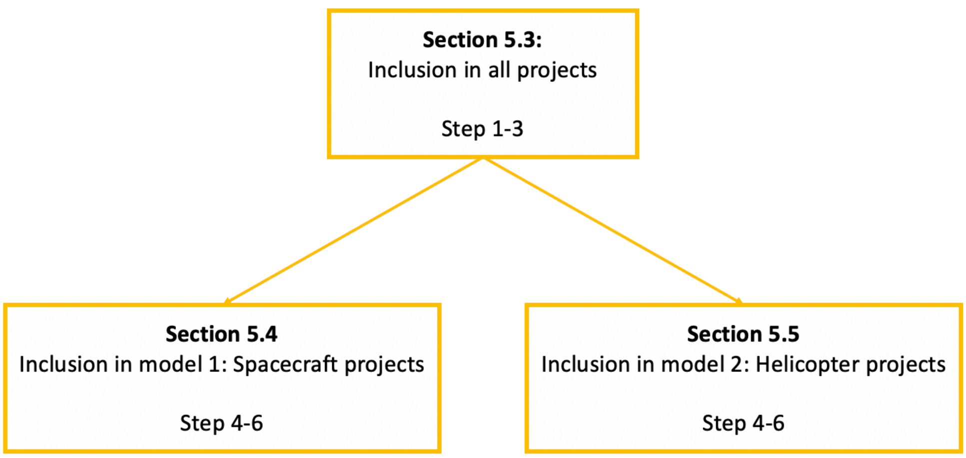

Figure 12: Structure of section 5.3-5.5

5.3 Inclusion in step 1-3

In this section the inclusion measures of both Spacecraft and Helicopter projects are discussed. This is done for step 1, 2 and 3 of the IIL.

5.3.1 Step 1: Intention

The first step of the IIL entails how the project's goal is chosen. I found that projects take measures to include SHFs in this, mainly by focusing on crops that are important for SHFs for economic and food security reasons, as well as by focusing on (known) issues that they face. Inclusion is thereby to some extent achieved, however could be improved. This is discussed below.

Choosing of crops

Most projects choose crops based on importance for food security and economy, leading to a focus on major staple and cash crops. Regarding food security, 13 out of 18 projects argue that the crop they work on has large importance for food security for SHFs in developing countries. The crop they focus on is a major staple crop that provides food for a large population (Interview 2,6,7,11,17,21,22,24). A project on making crops resistant to flooding indicates that "*We are starting in staple crops because rice for example, feeds over 3.5 billion people, half the world population*" (Interview 22). This project thus chose a crop that contributes to large-scale food security. Similarly, one of their criteria for interviewee 17 is that the crop is "*a big way into food security*". These examples show that projects choose major staple crops because of their importance for food security.

Besides food security, five interviewees choose cash crops because of their economic importance for the country or for SHFs (Interview 4,5,14,18,19). For example, Interviewee 19 explains that "*cocoa selling represents 35% of the exports earning of the country*". Another project focuses on cotton because: "*10% of our GDP is based on cotton and its products. So we selected cotton because it's economically very important for our country"* (Interviewee 4). These cash crops thus have significant economic importance in developing countries. Economic importance is also indicated by referring to providing income. Namely for coffee, which "*provides the main source of livelihood for about 125 million people globally*" (Interview 5). By focusing on economic importance, projects choose major cash crops that are largely grown in developing countries by SHFs.

Large scale food security and economic importance as the main criteria could help to explain the absence of projects on less cultivated varieties, such as various orphan crops (discussed in section 5.1). Major staple and cash crops are chosen over varieties that might be very important in a specific region or for minority groups only, causing exclusion for these SHFs. An exceptional project however works on orphan crop teff. Teff is the main staple crop in Ethiopia and Eritrea, grown by SHFs in those counties only (Cheng et al., 2017). The interviewee explains that she works on teff because of local importance: *"One thing I wanted to do was definitely focus on crops that are important in my home country (Ethiopia) [...]. Teff is one crop that's unique and that isn't cultivated in other parts of the world."* (Interviewee 14). For global food security, teff could be argued to be less important than for example rice, as teff is only a main staple crop in two countries. However, by considering importance on a smaller scale, a crop that is not a major global crop was chosen in this project.

Besides food security and economic importance, technological and organisational reasons for crop choice are articulated by three interviewees. For the former; the interviewee argues that rice is a good model plant with the practical benefit that *"it's really transformable, meaning we can do all the gene manipulations and other stuff in it."* (Interviewee 6). Findings in a good model plant can more easily create actual impact for SHFs (Interview 6). Concerning organisational reasons, a project chose cacao because of their partner's focus: "*In cacao, we had Mars Corporation come to us and say, well, here is some gift money to work on this"* (Interview 10). Similarly, a project on sorghum and millet chose for these orphan crops as their partner's mission is to work on these crops (Interview 23). The latter example shows that partnerships can also cause that orphan crops are chosen instead of major staple or cash crops. Technological and organisational reasons for choosing crops are however exceptions.

Overall, most projects choose crops based on their food security and economic importance. This leads to a focus on major staple and cash crops, that provide food or income on a large scale. These decisions can be classified as pro-poor: providing income and food for the poor, and equalizing: increasing income of a low-income group and with that changing socio-economic structures. For none of the projects crop choices were informed by ideas of fairness, for example by focusing on crops that are specifically beneficial for female SHFs or SHFs from minority groups.

<u>Choosing of traits</u>

To improve the chosen crops, projects work on specific traits. This too is important for inclusion, as some traits are more relevant for SHFs than others. There are two main ways in which projects choose traits, namely by solving a "widely known" issue or because their "collaborator knew" about the issue. In case of the "widely known" issue, 8 out of 18 projects focus on major diseases or pests (Interview 1,2,5,7,8,13,16,17,18,19). For example, one interviewee states that they "*looked at what the biggest problems were in the production of those crops, and how that could be solved by using CRISPR technology*" (Interview 11). Others do not even seem to actively look for major problems and took for granted the existence of such 'widely known' problems. When asked how they identified the problem they work on, one interviewee answers rather surprised: "*Oh, that problem has been identified by the field many years before I started my PhD*." (Interview 1). Two projects focus on a new disease for which attention is increasing as it is spreading rapidly (Interview 9,21). Projects thus mainly focus on traits that are widely known, such as (increasingly) major diseases or viruses.

Although focusing on widely known major issues is important and solutions are urgently needed, it can be doubted whether this focus will lead to inclusivity for all SHFs. Perhaps in a particular area, SHFs deal with issues that are devastating their yields but are not known by the global research community. None of the researchers for example said they consulted with specialists of a specific crop, grey literature on orphan crops and traits, or SHFs themselves, when choosing a trait. Studies have shown that scientist often assume that they know the challenges of the farmers, rather than that they consult farmers for this (James & Sulemana, 2014), and this is also what I found for selecting traits. Due to this, important traits might not be tackled.

For some projects this however seems to be partially solved by relying on knowledge of collaborators. Besides choosing "widely known" issues, projects choose traits based on that their "collaborator knew" about the issues. This was the case for 4 out of 18 projects. These collaborators are either based in developing countries, or are a CGIAR institute (Interview 2,4,9,13,21,23). For example, Interviewee 13 explains that through discussions with scientist of local labs, his project ended up working on major local problems. Including input of the collaborator can even make that certain traits are considered that would have otherwise not been considered at all. One interviewee explains about their collaboration with the CGIAR's International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Without this collaboration, the chosen trait would have otherwise not even been considered: *"It's really interesting working with ICRISAT because we do have a pearl millet program in India, but we really hadn't thought about focusing on rancidity. But in working with IRCRISAT, they really call it (rancidity) out the challenge for SHFs in India [...] And so it was really good guidance from ICRISAT on really what the trait targets were" (Interview 23).* Input of a developing country or CGIAR collaborator, can thus ensure that relevant SHF issues are tackled that are less widely known. Hereby inclusivity of intention increases.

One project has a more practical reason for the trait's focus, namely available knowledge and expertise (Interviewee 19). This interviewee explains to focus on black pod disease in cacao because this is his partner university's expertise. He said: "*So that's the reason why I focus on this disease because I know there are some research teams, some plant scientists working on this*" (Interview 19). This practical consideration is however an exception, as traits are mostly "widely known" issues, or because a "collaborator knew" about the issue.

The way in which projects choose traits can be seen as inclusive from a pro-poor point of view; known issues of the poor, SHFs, are tackled. Projects did not indicate to choose traits especially beneficial for disadvantaged groups nor that could change socio-economic structures; fairness and equalizing approaches are thus lacking.

For both choosing crops as well as traits, inclusion is limited is because no single project started by direct input of SHFs. SHFs were not consulted in the earliest phases of the projects, to identify what crops and traits were most relevant. Bentley et al. (2007) argues that farmer demand for innovation constantly changes and should be continuously monitored. Absence of such a process makes it questionable whether the projects focus on most relevant SHF problems. Inclusion of SHFs in process (step 4) from the very first moment would overcome this.

Literature also argues for such early stakeholder involvement in innovations. Upstream engagement could ensure societal acceptance of biotechnology (Wilsdon & Willis, 2004). However, it can be caught in the "Collingridge dilemma"; although technologies are upstream not yet path-dependent and can be altered based on stakeholders opinions, in early phases it is difficult to foresee downstream consequences (Ribeiro et al., 2018). Upstream engagement of SHFs can lead to research projects choosing different crops and traits than without such engagement. However, following the dilemma, acceptance and adoption is not certain as downstream consequences can differ from expectations. Nevertheless, upstream inclusion of SHFs in choosing crops and traits could increase the chance that the developed applications align with SHFs needs.

<u>Intentions beyond the crop and trait</u>

Above intentions are the case for both Spacecraft and Helicopter projects. However, only Helicopter projects have additional intentions beyond improving a certain crop and trait. Six out of thirteen Helicopter projects articulate goals of capacity building (Interview 1,2,3,9,13,14,17,19,21,23). They aim to build capacity for other actors to conduct gene-editing crop research. They thereby look beyond the scope of their projects, to create long-term impact. It is especially relevant that these six projects (also) build capacity in developing countries. In literature it is argued that for availability and accessibility of biotechnology in developing countries, national capacity in biotechnology research is critical (Cohen et al., 2004). By building gene-editing capacity in developing countries, Helicopter projects could thus contribute to this accessibility and availability.

Capacity building is by the projects considered as an imperative aspect of the project. It is for example a prerequisite for a partnership for interview 19: "*So, that is one of the things that we always insist on when we come to a partnership, because we want to also do capacity building.*" Other projects even describe capacity building as their main goal (Interviewee 3,9,13,23). For example, Interviewee 13 explains that capacity building is more important developing a crop:

"I'm more interested in doing capacity building than to really think I want to bring the first […] virus resistant cassava to Africa because obviously, it's going to be a one shot, and it's not going to be sufficient in the long run. […] Capacity building might be more a long term impact yes, but at least you have something that will be consistent" (Interview 13).

In similar lines, interviewee 23 explains that capacity building is their main intention:

"The original mission was really to enable their scientists; it was really never about us delivering traits for them. It was really about democratizing the technology […]. So that if you look at the next trait they want to deliver, they can do it in their own labs, and they wouldn't need us as a partner" (Interview 23).

Helicopter projects thus emphasize the (long-term) importance of capacity building for other actors to use gene-editing to deliver crops and traits.

Capacity building goals create inclusion on higher steps of the IIL, namely in step 5: structure. For example, by contributing to human infrastructure in developing countries. How this capacity building is executed by Helicopter projects is discussed in section 5.5.2.

The intention of capacity building in developing countries is an equalizing approach; it changes socio-economic structures. Namely, instead of R&D being concentrated in rich countries (as we saw before), R&D can also be conducted in poor countries. The projects did not articulate intentions beyond improving a crop and trait related to pro-poor or fairness approaches.

5.3.2 Step 2: Consumption

The second step of including SHFs is consumption. This entails the targeted consumers that will grow the crop as well as how the crops will reach these consumers. All projects take inclusion measures in this step, by targeting SHFs and with measures for accessibility and affordability. How they fulfil inclusion, and the shortcomings in doing so, are explained below.

Targeted consumers

The targeted consumer group for almost all projects is SHFs in developing countries. 16 out of 18 projects do not articulate a more specific target group than SHFs in general, like SHFs of a minority group or women SHFs. When asked about a specific target group within SHFs, interviewee 6 answered *"Um, I have no clue about that. For us it's in general"*. Projects indicate to have not yet thought about a more specific target group (Interview 1,6,14), this might thus only be done in a later phase. Targeting all SHFs though ties in with the finding of step 1 (intention) that most projects focus on major crops due to large scale food security and economic importance. Targeting all SHFs that grow the crops also can lead to largest impacts.

This target strategy shows a pro-poor approach; targeting the generally poor group of SHFs. It could also lead to equalizing impacts, as by targeting the low-income group of SHFs, and not richer large-scale farmers, socio-economic structures could be changed. Projects thus take pro-poor and equalizing approaches with their general SHF focus.

Only two projects have a more specific target consumer than SHFs, namely specific countries or subgroups within SHFs. These are both Helicopter projects. Firstly, a project on rice focuses on countries where the regulatory framework looks most promising (Interview 8). This however remains general; all SHFs in these countries. Secondly, a project on maize specifically targets SHFs in areas that are generally not well served by markets (Interview 2) and women (Interview 21). For example, Interviewee 21 targets women as they are more attentive about the harvest than men, because they are concerned about providing food for their children. Targeting disadvantaged groups in this project relates to a fairness approach. Targeting women is especially relevant as women have found to be constrained in adoption of agricultural technologies (FAO, 2011). The barriers for women are however unlikely to be overcome by the gene-editing projects, as this project is only an exception.

Accessibility

For SHFs to consume the crop, an inclusive dissemination strategy is necessary to ensure accessibility. All projects collaborate with either governments, local companies, or CGIAR institutes in developing countries for dissemination. They thus do not disseminate the crops themselves but existing systems for this.

Half of the projects plan to collaborate with governments in developing countries to disseminate the crops by their existing agricultural research- and extension systems. For example, interviewee 14 says about the government that they are "*definitely working with them, to try to get on that platform that's already there*". Interviewee 2 explains that governments will be in charge of dissemination the seeds *"It would be [...] their departments of agriculture, to basically spread the seeds to the different localities or to the farmers remote area. So that's something where we probably wouldn't be on the driving seat".* This strategy of using the government's systems for dissemination is argued to be a suitable to reach SHFs. For example, as *"the governments know where the farmers will be able to be reached*" (Interview 1). Projects thus use existing systems of developing countries' governments for making the crops accessible for SHFs.

Besides the governments, five projects work with local companies for dissemination (Interview 4,5,7,14,20,21). For example, interviewee 20 explains: "*The seed company will do the seed bulking and also will bring the seed to the farmer*". Similarly, Interviewee 21 also works with local companies: "*We work with seed distributors in the region [...] and allow them then to distribute that seed to these farmers and through their own business systems."* Dissemination by local companies is argued to be a suitable strategy, because they do distribution and commercialization regularly (Interviewee 15) and have the connections to reach SHFs (Interview 21). The projects thus use existing systems of local companies to disseminate crops to SHFs.

Besides governments and local companies, three projects plan to work together with CGIAR institutes for dissemination (Interview 11,17,23). These projects explain that CGIAR institutes "*are experts*" (Interview 17), "*have an intimate relationship with SHFs*" (Interview 23) and "*are already set up to provide germplasms"* (Interview 11). The capacity and expertise of CGIAR institutes are thus used for dissemination. Interviewee 11 refers to this as "piggybacking". By collaborating with CGIAR institutes, the projects aim for SHF access.

Using these existing systems can be seen as a pro-poor approach; systems that are in place for reaching the poor are used. This strategy though has its shortcomings. It is uncertain whether by using the systems of governments, companies or CGIAR institutes, accessibility for all SHFs is ensured. This is explained by interviewee 13; "*So if you go to African countries there is always a national program on this or that crop, but this [...] does not have the infrastructure to disseminate those crops*". Existing systems might thus not create access for all SHFs. Relying on existing systems is logical as research projects cannot be expected conduct everything themselves. However, SHFs that currently are not reached by existing systems are unlikely to now benefit. For example, SHFs in most remote places or in countries with poorly developed systems, will likely remain excluded. This strategy thus might only limitedly ensure access.

Five projects show additional measures to the above approach, by which possibly accessibility can also be ensured for SHFs not reached by existing systems. Two Helicopter projects work on improving or establishing a seed system in countries where the system is inadequate (Interviewee 8, 9). Interviewee 8 will work with local partners in Africa to set up a disseminating system for their disease resistant rice seeds. Interviewee 9 works to improve the seed system for disease resistant maize seeds: "*we're trying to work ahead of time with Kenya especially, in other countries eventually, to try to improve the seed system. So these seeds are more available."*. These projects are thus putting additional effort in ensuring that the seeds are accessible for SHFs. This could be seen as an equalizing approach where projects work on structural changes to increase accessibility for the low-income group of SHFs.

Furthermore, Interviewee 2 explains how rural communities in Kenya that are generally not well served by markets will be reached through selling small packages of maize seeds in small shops, called stockists. He explains that "*these are the most widespread ways of reaching into rural communities*". This is done by developing relationships with these stockists (Interview 2).

Two projects rely on informal systems. Interviewee 1 explains that cassava is distributed via informal networks, and by this the new variety can spread organically among SHFs. Interview 6 aims to involve SHFs in distribution, they could help with spreading the seeds. Relying on informal systems could grant access for SHFs outside of the formal systems. An estimated 90% of SHFs access seeds through informal seed systems (McGuire & Sperling, 2016). These five exceptions show how projects can increase access for otherwise excluded SHFs. None of the projects however have specific measures for access for historically disadvantaged groups; a fairness approach is not found.

<u>Affordability</u>

Besides accessibility, SHF face another barrier for consumption: affordability. To ensure affordability, almost all projects have included considerations of price in their projects. With one exception, projects promise to offer their crops for free or low prices. For this exception, the private actor in charge of dissemination will set the price (Interview 4). All other projects though have affordability measures. Four interviewees explain that the crops will be probably or practically free (Interview 1,10,11,14). Two projects indicate that the crops will be very cheap (Interview 4,20), for instance: "*it will be actually given to farmers at a very low cost*" (Interview 20). Other projects refer to market prices and indicate that their crop will be similarly priced or at least not more expensive than other crops (Interview 2,8,14,21). Projects thus mainly consider prices ranging from zero to market average. With this they aim for affordability for the generally poor group of SHFs; a pro-poor approach.

To realise affordable prices, projects depend on access to funding. For example, interviewee 8 referred to a governmental program needed to cover the gap between the cost- and market price. Interviewee 5 explains that financial aid is necessary for selling at affordable rates. Though projects plan to offer the crops for free or maximum average market prices, this is thus still dependent on whether the projects have funding for this. This makes it less certain that affordability will be achieved.

However, even when the crops have a low or average market price, affordability for the most resource-deprived SHFs is not ensured. For the green revolution, a common criticism is that the poorest farmers in developing countries could not afford improved varieties, which increased inequality between farmers (Gonzalez, 2006; O'Gorman & Pandey, 2010). Especially women farmers are found to have limited financial resources and access to formal credit (Niles & Carranza, 2019). With the lens of distributive justice, unaffordability could thus lead to widening of the income gap (equalizing), as well as the gender gap (fairness). Offering crops for low or average market prices might not suffice in preventing unaffordability for those groups. Projects have to ensure funding to safeguard a real affordable price for all SHFs. Currently, fairness and equalizing inclusion are only shown by the few projects that aim to offer their crops for free. None of the projects however take structural measures to ensure affordability for low-income groups (equalizing), neither do they ensure affordability for historically disadvantaged groups (fairness).

This section shows that though the projects take several inclusion measures, inclusion is not ensured as mostly existing systems are used for accessibility and low prices are possibly not affordable for all SHFs. Furthermore, the general SHF consumer target decreases the chance of certain groups of SHFs to benefit. Mostly a pro-poor approach is followed and equalizing and fairness measures are limitedly taken. However, some exceptional projects have additional inclusion measures. This could thereby lead to achieving the intended impacts of the projects, which is explained in the next section.

5.3.3 Step 3: Impact

Besides for intention and consumption, also for impact I found that the projects take measures for inclusion of SHFs. But again, there are limitations. As the projects are not in the commercial phase of cultivation of the crops by SHFs, I analyse the intended and expected impacts on SHFs. Besides impact on SHFs, also other prospected impacts are strived for by the projects, such as environmental benefits (Interview 5,12,18,19,20,22). This research however focuses specifically on SHFs, therefore this section discusses SHF impacts.

Analysing the projects on SHF impacts reveals that gene-editing is mainly used for a particular type of inclusion; economic impacts and contributing to food security. This is in line with step 1: intention, where was discussed that projects choose their crops mainly based on economic importance and food security criteria.

Economic impacts are strived for in three ways; by increasing yields, reducing costs and adding value to the crops. Firstly, increased yields will lead to increased income of SHFs (Interview 1,3,10,14,22). For example, a project on cassava explains their goal as *"to improve the yields for the farmers so that farmers who grow cassava have a higher income"* (Interview 1). Secondly, reducing production costs will increase SHF income, because less inputs are required (Interview 3,4,11,16,20). For instance, Interviewee 4 explains that spraying only 50% of the previous amount of pesticides will reduce production costs. Thirdly, projects aim to add value to the crop, which leads to a higher income (Interview 1,3,4,5,9,13,14,18). Value is added for example by improving quality or flavour (Interview 3, 9) or adding industrial applicability (Interview 1,9,13,14). For the latter, interviewees explain that they alter cassava's starch content so cassava becomes useful for the starch industry (Interview 1, 13). This new market opportunity would allow cassava SHFs to ask higher prices (Interview 1). Another project develops a low caffeine coffee variety. Currently, processors make regular coffee into low caffeine coffee. With a low caffeine variety:

> "*you are basically shifting value from the processors to the growers. So the goal was saying, okay, I'm saving you, the processors, 50 cents. Now I want you to give me 30 cents more for my coffee. So, we're basically allowing these millions of farmers to make more profit. We've shifted kind of the value to the field*" (Interview 5).

Making coffee low-caffeine thus adds value, allowing SHFs to get a higher income. Another way of value-adding is by developing a rice variety that does not emit methane. The interviewee explains that this could increase SHF income as preventing methane emissions brings opportunities for earning and selling carbon credits (Interview 22). Through adding value to the crop, increasing incomes of SHFs is thus strived for.

Looking at this with a distributive justice lens, increasing income can be seen as both pro-poor as well as an equalizing approach. By increasing income of generally poor SHFs, poverty can be reduced (pro-poor). Besides, this could decrease vertical inequality as the income of the low-income group of SHFs is increased which could change socio-economic structures (equalizing).

The second main impact projects strive for is food security (Interview 1,2,6,7,9,10,16,19,21, 22,23). This is done through improving yields and reducing risks. For the former, Interviewee 7 explains that improved yields of maize can impact 70% of the Kenyan population involved in farming. He said: "*think of that many people getting a boost in productivity […] it can be very meaningful for food security for these countries*". For the reducing risks, Interviewee 16 explains the importance of resistance to cassava brown streak disease (CBSD). Many SHFs use cassava as a backup for food, as you can leave it in the soil for an indefinite period. He explains:

"*You have these SHFs whose primary crop fails, and they go to dig up their cassava that they've essentially put in the bank for a rainy day. […] And if it's affected by CBSD, that's really devastating. They've lost their last line of defence for feeding themselves and their family.*" (Interview 16).

Taking away risks of crop failure thus also improves food security. Striving for food security impacts can be categorised as a pro-poor distributive justice approach. It alleviates the conditions of poverty by ensuring food for SHFs and their families.

Besides impacts on income and food security, improved quality of life is strived for. Projects aim for this firstly, by reducing (hard) labour (Interview 3,4,9,12,14). Interviewee 4 explains that in cotton farming in Pakistan, pesticide spraying is not mechanised. By reducing the needed frequency of spraying, labour could be decreased. Secondly, reducing pesticide spraying will improve health (Interview 11,16) as the protective gear needed for applying pesticides is often not used (Interview 11). Health is also improved by lowering toxicity levels of the crop (Interview 11,12). Thirdly, even reducing suicide levels (Interview 11) is mentioned as a possible impact. Projects thus aim to improve quality of life aspects. This is a pro-poor approach, as it alleviates the conditions of poverty.

Furthermore, some interviewees mention impacts for SHFs' children. They explain that because of the improved variety, SHFs' children be better supported for education and pursuing a career (Interview 1,2,7,13,14,18). This is an equalizing impact, as it could change socio-economic structures. Education can lead to better jobs and a higher income for SHF households.

The above shows that Spacecraft and Helicopter projects aim for pro-poor and equalizing impacts. However, with this full inclusion is not achieved. Projects could have also strived for other impacts. For example, creating benefits for historically disadvantaged groups, such as women or ethnic minorities. Only five projects mention such impacts. These are all Helicopter projects. Three Helicopter projects aim to create impact for women; empowering them with an income (Interview 2), reducing their hard work (Interview 9) and reducing health burdens that now fall mainly on women/children (Interview 12). One Helicopter project aims to reduce child labour (Interview 14): *"And so, I think and hope that it will escalate into maybe that those kids don't have to spend so much time weeding"*. A Helicopter project on cassava hopes to lower racial disparity, as cassava SHF are typically black, whereas large scale farmers are typically white (Interview 1). These five Helicopter projects are thus striving for benefits for historically disadvantaged groups; a fairness approach. However, as these projects are exceptions it is unlikely that gene-editing will create fairness impacts.

Summarizing, projects mainly strive for increasing income and food security, and sometimes improving quality of life and education for SHFs children. With these pro-poor and equalizing impacts, urgently needed benefits will be created for many SHFs, as SHFs are generally poor and face food-security issues (FAO, 2015). A few Helicopter projects however show that a fairness approach on benefitting historically disadvantaged groups is possible. However, these projects are exceptions. Concluding, the projects show inclusive prospected SHF impacts, however shortcomings are present.

5.4 Inclusion in step 4-6 of Spacecraft projects

The way in which inclusion was (not) achieved in step 1-3 was similar for all projects. However, for the highest three steps of the ladder, I found two inclusion models. One group of projects does not (yet) include SHFs in the process (step 4), which I call Spacecraft projects. Spacecraft refers to that the project teams are far from the SHFs; they fly in space. They develop the crops in isolation, without speaking to SHFs, and only get to the ground after they have finished the crops (landed). The other group of projects involves SHFs in earlier process phases (step 4), which I call Helicopter projects. In this section step 4-6 of the Spacecraft projects is discussed.

5.4.1 Step 4: Inclusion of Process of Spacecraft projects

This section describes inclusion of SHFs in the processes of Spacecraft projects, using the two sub-ladders of the moment and form of inclusion. The highest step of the moment sub-ladder is achieved when SHFs are included at invention, rather than only at distribution. The form of process inclusion is maximized when SHFs are controlling the project. For both sub-ladders, Spacecraft projects show shortcomings on inclusion.

Spacecrafts do not include SHFs in early phases of the project. They do not have measures for involving SHFs in the invention and design of the crop (sub-step D and E in Figure 13). In early phases, the projects for example do not inform or consult SHFs. Figure 13 shows that for the form of inclusion, projects only plan to involve SHFs in later phases (sub-step 1-3) or are not planning this at all (sub-step 4 and 5). Concluding: process inclusion of SHFs is absent in early phases of Spacecraft projects.

Spacecraft projects argue that early phases do not allow for SHF inclusion (Interview 6, 10, 15). For example, Interviewee 6 explains: *"So we haven't got to that point where we can involve farmers, right. It's still at the technology development stage".* The same line of reasoning is given by interviewee 10. When asked about contact with SHFs, he replied: *"Not yet, because we still try to finish the technology. […] It's still in the immature period, we have not yet tested in the field".* The projects thus indicate that because the crops are not yet fully developed, they do not engage with SHFs.

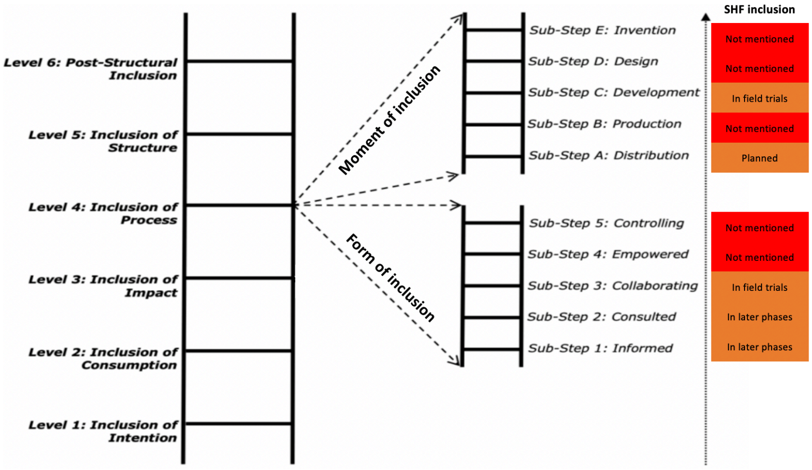

Figure 12: Sub-ladders of process for Spacecraft projects

The above line of reasoning suggests that in a later phase, SHFs could be included in the process. Spacecraft projects indeed plan to involve SHFs when the crop is (more or less) finished (Interview 6,10,15). For example, "*when you have something in hand*" (Interview 15), or once the technology is more than 95% efficient (Interview 6). In this later phase, they plan to involve SHFs in several ways. Interviewee 6 plans to inform SHFs (sub-step 1), consult SHFs for information (sub-step 2) and involve SHFs in distribution, by spreading of seeds (sub-step A). The latter could generate additional income for SHFs and thereby reduce income inequality; an equalizing approach. These plans can create inclusion, however, informing, consulting and distribution are low steps of the sub-ladders (Figure 12). With these plans, inclusion remains limited.

Spacecraft projects furthermore plan to collaborate with SHFs (sub-step 3) by involving SHFs in field trials (Interview 6, 10). This is again an equalizing approach, as it could increase SHFs' income. Literature on Participatory Plant Breeding (PPB) however shows that also in the traditional, not-inclusive, breeding system crops are tested in farmer's fields (see Figure 4) (Ceccarelli & Grando, 2007). Morris & Bellon (2004) furthermore note that inclusion of farmers in field trials is not a high mode of participation. Collaborating with SHFs in field trials is thus a limited inclusion form.

Overall, Spacecraft projects do not include SHFs in any of the choices made in early phases of inventing, designing and developing the crops. They only plan to involve SHFs once the technology is finished, such as for testing and dissemination. This seems to indicate that SHFs are not included in shaping the technology. The choices made in using gene-editing is hence left entirely to experts, like choices of crop or trait. As explained in section 5.3.1, early engagement of SHFs is desirable for ensuring suitability. It could influence choices before the project is path-dependent (Ribeiro et al., 2018). However, a pro-poor process inclusion approach that ensures suitability is absent. A fairness approach is also lacking; Spacecraft projects do not engage with historically disadvantaged SHFs. Only some, rather limited, equalizing measures are planned. Profound inclusion such as SHFs deciding over structural issues, for example ownership, was though absent. To conclude, Spacecraft project's (planned) measures for including SHFs in process are very limitedly inclusive.

5.4.2 Step 5: Inclusion of Structure of Spacecraft projects

Similar to step 4, also in step 5 Spacecraft projects take limited inclusion measures. Inclusion measures in step 5 would build a favourable structure for gene-editing research to create benefits for SHFs. As explained in the theory, this can be done in six different ways. For each of these six categories, the (absence of) measures by Spacecraft projects is elaborated upon.

Legal/policy infrastructure

All but one of the Spacecraft projects are not involved in trying to shape the legal or policy infrastructure (Interview 6,15,16,20). Different reasons are given for absence of lobbying activities: lobbying is not the role of scientists (Interview 6), will only happen in a later phase (interview 20) or that the interviewee is not invited to "such official meetings" (Interview 6). There is one Spacecraft project that does try to shape regulation, namely by informing the Indonesian ministry of Economy about CRISPR (Interview 10). Aside from this exception, Spacecraft project do not try to influence gene-editing regulation.

The absence of activity in this step can have implications for SHFs. In most developing countries it is not decided how gene-edited products will be regulated, such as whether they will fall under GMO laws (Schmidt et al., 2020). GMOs are banned in many developing countries and overregulated in others, the latter causing delays in the development of GM crops (Smyth, 2017). A GMO project on rice was delayed over 10 years due to the regulatory requirements (Potrykus, 2012). A similar situation could appear for gene-editing, which demonstrates the importance of a low regulatory burden for gene-edited crops (Schmidt et al., 2020). This would ensure that in developing countries gene-edited crops could enter the market so the poor have access to the crops (pro-poor approach). The absence of most Spacecraft projects in lobbying for this thereby is an important limitation.

Next to absence of pro-poor approaches, fairness and equalizing measures are also not found. Projects do not try to change horizontal inequalities, such as policies for including women in research (fairness), neither lobby for structural changes of gene-editing research that could reduce vertical inequalities (equalizing).

Institutional infrastructure

Only one Spacecraft project works on an institutional infrastructure (collaborative structures and organisations) that supports inclusive gene-editing. This project on rice formed a research consortium with several actors (Interview 20). So far, this consortium though only has one project. Possibly in the future this consortium could also work on other SHF relevant traits or crops. This project is an exception though, all other Spacecraft projects do not take measures for a supportive institutional infrastructure. Equalizing, fairness and pro-poor inclusion is thus not achieved.

Human infrastructure

Spacecraft projects are only limitedly involved in building a supportive human infrastructure. The projects are mostly only involved in training and supervising students and researchers in developed countries (Interview 6, 15, 16) or for continuation of their research group (Interview 20). Though training in developed countries might eventually lead to more inclusive gene-editing research, this is rather indirect and uncertain.

Especially human infrastructure building by training researchers in developing countries relates to inclusion. In a direct way, human capacity building in developing countries could structurally change where gene-edited research is executed. Namely, also developing countries would have capacity for this, instead of R&D being concentrated in rich developed countries. This equalizing approach is however only found in one Spacecraft project. This project's interviewee, based in Indonesia, explains that for training they: "*selected for the last years approximately 17 students […]. They came from different universities in Indonesia.*" (Interview 10). These training activities increases human capacity for gene-editing research in Indonesia. However, this project is an exception.

Indirectly, human infrastructure in developing countries could lead to suitable crops being developed for SHFs. Capacity for biotechnology research in developing countries is namely critical for accessibility and availability of biotechnology crops in these countries (Cohen et al., 2004). The pro-poor impacts this could indirectly lead to are thus, aside from the above mentioned exception, absent. Also, a fairness approach is lacking; projects for example do not specifically train historically disadvantaged groups, such as women researchers.

<u>Financial infrastructure</u>

None of the projects work on contributing to a beneficial financial infrastructure for gene-editing R&D. The projects are themselves reliant on funds for their research, therefore it is unsurprising that they do not fund other projects. Projects could have tried to influence the financial infrastructure in other ways though, but a pro-poor, fairness and equalizing approach for this are all lacking.

<u>Technological infrastructure</u>

Spacecraft projects mainly took two measures to enable technology transfer, firstly by engaging with other research groups, and secondly by allowing others to use their patents. For the former, all but one Spacecraft project share their technology and technical know-how with other scientists beyond their project (Interview 6,10,15,20). Interviewee 16 is an exception and does not engage with other researchers.

Engaging with other researchers is though particularly relevant with researchers from developing countries. As explained before, enabling gene-editing research in developing countries could change socio-economic structures (equalizing) and indirectly lead to more SHF benefits (pro-poor). Only one project has technology transfer activities in developing countries. Interviewee 10 explains that they invited: "*the […] university, we invited our partners from […], and also several independent researchers. And then we discuss and we present each other the progress of CRISPR*" (Interview 10). This project thus engages with other researchers in developing countries to share gene-editing knowledge. This is however an exception; equalizing and pro-poor approaches are by all other projects lacking. Also, a fairness approach is not found. Overall, Spacecraft projects have limited inclusion measures of technology transfer to other researchers.

Secondly, technology transfer is not hampered by intellectual property right (IPR) barriers. Some projects do have applied for patents, but these patents will not be enforced for developing country applications (Interview 6,16,20). Other Spacecraft projects have not applied for patents (Interview 10,15). Both can be seen as an equalizing approach as the system of IPR that could create barriers for technology transfer is circumvented. Technology can thereby more easily spread to for example actors that would not have the resources for a patent license. This could shift biotechnology research to less resource-full actors. However, a more profound equalizing measure would structurally change the IPR system. Efforts for this are not found in Spacecraft projects. Overall, with the project's measures, IPR will not be a barrier for new projects that focus on SHFs in developing countries.

Public support

Ensuring public support in developed countries is by Spacecraft projects done in different ways. Projects give talks about gene-editing technology and their projects (Interview 15,16) and participate in online forums (Interview 6). One project also reaches out to the wider population through media:

"*There's a lot of interviews, whether it's through newspaper, TV or radio that has been done in the past. We kind of introduced this project to the people and kind of give them awareness of what we're trying to achieve, and what would be the benefits of outcome. So I think in that sense, we kind of tried to reach out and educate the public of why we're doing this project*" (Interview 20).

By the media this project thus tries to educate the public in developed countries. These activities can be classified as pro-poor, as they aim for public support for pro-poor gene-editing of crops. None of the Spacecraft projects specifically elaborated upon getting public support of gene-editing for or by historically disadvantaged groups (fairness), nor for the change of socio-economic structures (equalizing). Public support measures are thus limited to acceptance of using gene-editing for pro-poor benefits.

Above measures for public support for gene-editing in developed countries is important so crops developed by SHFs can be exported to these countries (Nielsen & Anderson, 2000). Efforts to educate the public and show them the benefits that are undertaken by Spacecraft projects could possibly prevent for gene-editing to follow the same path as GMOs, which have a bad reputation among the public in developed countries (Marris, 2001).

However, a shortcoming is that public support activities are lacking in developing countries. Support by SHFs that will grow gene-edited crops, as well as by the wider public to ensure acceptance for domestic consumption is important. A study in Sub-Saharan Africa on GM cowpea shows that consumers that were aware of GM technology through media or radio, were more likely to approve GM crops (Kushwaha et al., 2004). Such activities in developing countries are though absent in Spacecraft projects. Public support in developing countries is thereby uncertain.

Summarizing step 5:

Spacecraft projects have minimal inclusion measures in this step; shortcomings are evident in all six structure categories. Spacecraft projects thus only limitedly contribute towards a favourable structure in which SHFs are included in gene-editing.

5.4.3 Step 6: Post-structural Inclusion of Spacecraft projects

For the highest step of the IIL, Spacecraft projects again have limited inclusion measures. This step entails post-structural inclusion of the frames of knowledge and discourse of key actors in the innovation system. Indications for inclusion are measured by 1) inclusion of SHF knowledge, 2) communication in SHF language and 3) the goal of the wider organisation. Spacecraft project only show very limited inclusion in all three aspects.

Firstly, Spacecraft projects are very limitedly inclusive in terms of including SHF knowledge. Only one project considers SHFs knowledge (Interview 10). All others do not include SHFs knowledge, which could be expected as Spacecraft projects do not consult SHFs to acquire this knowledge (step 4: process). There is thus a lack of including knowledge of the poor (pro-poor approach), as well as of historically disadvantaged groups (fairness approach). Projects are also not organised in a structure in which all types of knowledge are always included (equalizing approach). Spacecraft projects thus lack post-structural knowledge inclusion.

Secondly, Spacecrafts do mostly not communicate in local languages of SHFs. They all use English for (scientific) communication (Interview 6, 10, 15, 16, 20). This excludes SHFs that do not speak English from being informed about the projects. This relates to public support in step 5: structure: providing information in the local language could ensure acceptance of the public in developing countries, and SHFs in specific. Exceptionally, Interviewee 10 gives speeches and webinars in Indonesia's national language. However, in general, Spacecraft projects do not include local languages of SHFs in their communications. Communication is thus not targeted to the poor SHFs, neither in languages of historically disadvantaged groups, let alone that projects have a structure in which communicating in all languages is common. Respectively pro-poor, fairness and equalizing approaches are thus absent.

Thirdly, for the goals of the organisation the project is part of the results are mixed. For two projects, improving agriculture for developing countries is also the mission of their organisation (Interview 10, 20). They share a pro-poor goal of benefitting poor farmers in developing countries. For example, the project is part of a consortium that focuses on improving rice for SHFs in developing countries (Interview 20). However, for the remaining three Spacecraft projects, their organisation's goal is not deliberately to achieve inclusion (Interview 6, 15, 16). Interviewee 16 for example explains: "*To be honest, I think majority of the people here […] is trying to answer some basic science questions that could have implications for improving agriculture in general*". In this instance, the organisation's focus is thus on basic science for agriculture in general, not on benefitting SHFs in developing countries in specific. Besides, none of the projects organisations has goals to reduce vertical or horizontal inequalities, showing an absence of equalizing and fairness approaches. Concluding; the organisations of Spacecraft projects are only partially inclusive in their goals.

Overall, post-structural inclusion is thus very minimal. Positively, almost half of the project's organisations have inclusive goals. However, other inclusion aspects are lacking, such as inclusiveness in knowledge and language. Post-structural inclusion by Spacecraft projects is thus not achieved.

5.5 Inclusion in step 4-6 of Helicopter projects

Previous section explained how inclusion was (not) achieved for Spacecraft projects in step 4-6 of the ladder. This section follows the same structure in discussing this for Helicopter projects. Contrary to Spacecraft projects, Helicopter projects do include SHFs in their process in early phases. Helicopters fly closer to the ground and can land in developing countries to speak with SHFs. This is explained in the following.

5.5.1 Step 4: Inclusion of Process of Helicopter projects

In this section, the way in which Helicopter projects include SHF in their process is discussed using the two sub-ladders of step 4. This is visualised in Figure 13. Helicopter projects are distinguished from Spacecraft projects as they do include SHFs in early phases, which Spacecraft projects do not. Helicopter projects include SHFs in their process in two ways: consulting and informing.

Firstly, all Helicopter projects acquire information from SHFs (sub-step 2: consulted). They ask SHFs a wide range of questions. For example, in a project on virus resistant cassava: *"At one farm that we visited, we would ask them what they were growing, how their field was set up, and […] whether they had severe pressure for the virus on their cassava plants"* (Interview 1). Similarly, a project on bacterial blight resistance explains: "*I usually ask for bacterial blight. […] So I'm looking for symptoms. And if I see them, I'll ask about management practices they use, especially fertilizer use. I'm always interested in how much they harvest, which varieties they grow, and how they reach markets, and if they've grown for their own consumption or for other purposes"* (Interview 8). These quotes show that SHF information is acquired about the trait, as well as wider aspects such as farming practices and the market. Helicopter projects thus consult SHFs for acquiring a wide range of information.

Secondly, some projects inform SHFs, whereas others deliberately do not (sub-step 1). Some projects inform SHFs about their project and aims (Interview 1,2,5,21). Interviewee 5 finds this important for the next step, commercialisation, as by this SHFs "*already had the time to consider and to understand what it is that we're doing*.". Informing SHFs before the crop is finished can hereby lead to quicker adoption. These Helicopter projects contrast Spacecraft projects which do not inform SHFs until the crops are finished. Other Helicopter projects however also take the latter approach and do not inform SHFs yet either (Interview 7,8,21). They argue that informing SHFs too early could catch negative media attention (Interview 8) or create too much hope for SHFs (Interview 21). Interview 21 explains that when you inform SHFs too early *"you start telling somebody who is hungry about food and then you don't even have that food"*. This can damage the trust of SHFs if the project fails (Interview 21). Concluding; some Helicopter projects already inform SHFs, whereas others, similar as Spacecraft projects, only inform SHFs later on. Inclusion in informing SHFs is thus not always achieved.

The channels by which projects inform and consult SHFs is rather diverse. Most often projects visit SHFs on their farms (1,5,8,13,17,18,19,21,22). Besides this, events and programs are organised. For example field days (Interview 2,21), farming education programs and workshops (Interview 3), farmer days (Interview 4), cooperative farming projects (Interview 4), farmer field schools (Interview 19,21), social gardens (Interview 21), participatory breeding activities (Interview 19), demonstrations (Interview 21) and agricultural shows/trade fairs

(Interview 21). Helicopter projects thus have diverse channels for SHF contact. Sometimes SHF contact is indirect: through local collaborators who actively engage with SHFs (Interview 2,7,8,9,12,14,22). Local collaborators "*talk to hundreds of farmers*" (Interview 9) and collect samples/surveys (Interview 1,7,9). One project takes a fairness approach; their farmer field day are mostly attended by women (Interview 21). This is an exception however; other projects do not deliberately engage with historically disadvantaged groups. To sum up; the projects directly and indirectly engage with SHFs by amongst others farm visits, programs and events.

The information acquired by engaging with SHFs is used to ensure that suitable crops are developed. The information is incorporated in the project (Interview 1,2,4,7,9,13,14,17,21,22), such as for product design (Interview 4,7,9,13,21,22). This shows that Helicopter projects, in contrast to Spacecraft projects, involve SHFs in the design phase (sub-step D). Helicopter projects argue that it is important to acquire and use this information in early phases, before the product is finished. Interviewee 21 elaborates that this is necessary because *"If you just go and lock yourself somewhere and develop a product, then you go to the people, then you will be surprised because yes, you have a very good product, but that is not what they want"*. Similarly, interviewee 5 also indicates that contact with SHFs is necessary for suitability "*to make sure that we are developing the right types of products*". This relates to a pro-poor approach of ensuring that the crop will benefit the, generally poor, SHFs. SHF contact is necessary as such insights you do not get from behind your computer; "*you need to go out"* (Interview 8). By "going out" and consulting SHFs for information, Helicopter projects thus try to increase the chance of developing a crop suitable for SHFs

Besides the inclusion of SHFs in early phases, Helicopter projects also plan to include SHFs in the future. Firstly, they are planning to do field-trials with farmers (12,14,19,20), similar to Spacecraft projects. This can lead to inclusion of sub-step 3: collaborating and could generate additional income for SHFs (equalizing). However, as explained for Spacecraft projects, this is a limited form of inclusion. Secondly, projects want to speak with SHFs more often (Interview 6,9,12,14) and organise SHF events (Interview 5). Thirdly, one project specifically explains that it would be important to speak with women instead of men, but that this is difficult for social reasons (Interview 8). The latter shows a fairness approach of including a historically disadvantaged group. Summarizing; Helicopter projects plan more future measures to include SHFs of informing, consulting and collaborating.

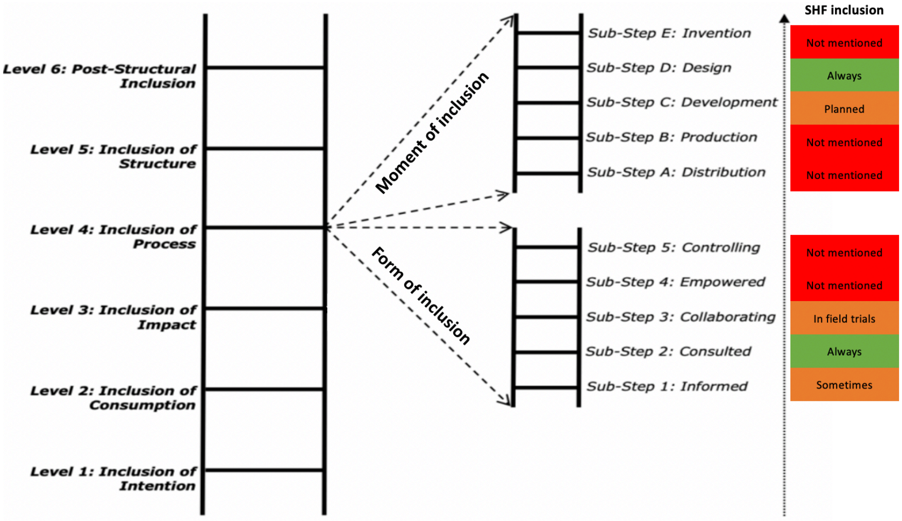

Figure 13: Sub-ladders of process for Helicopter projects

The analysis above demonstrates that Helicopters include SHFs in processes in various ways and are more inclusive in this than Spacecraft projects. However, also Helicopter projects' measures have shortcomings. Figure 13 shows that Helicopter projects mainly consult SHFs (sub-step 2), sometimes inform SHFs (sub-step 1) and plan to collaborate with SHFs in field trials (sub-step 3). Absent is inclusion of SHFs in the form of empowerment and controlling (sub-steps 4 and 5). This means that SHFs do not have the power to influence or control the project, for example by (being part of) taking decisions. Inclusion of these sub-steps could lead to structural equalizing impacts, as by this SHFs could for example decide over ownership issues and distribution of benefits. Inclusion in the two highest sub-steps are thus not achieved; the form of inclusion is by Helicopter projects not maximised.

The moment of inclusion is not optimal either. Positively, many Helicopter projects already include SHFs in early phases of design and development (sub-step C and D). However, similar to Spacecraft projects, none of the Helicopter projects started with involvement of SHFs. Inclusion in intention (sub-step E) is lacking. Similarly, section 5.3.1 explains that none of the projects chose their goals by speaking with SHFs. Furthermore, inclusion in distribution and production is absent. Inclusion of SHFs in these steps could change socio-economic structures. For example, if SHFs would sell seeds, this could shift some of the income from seed companies to SHFs (equalizing). Besides the form, also the moment of process inclusion is thus limited.

Regarding distributive justice; projects thus mainly take pro-poor approaches and some limited equalizing measures. Only two projects have fairness measures. Overall, though Helicopter projects engage with SHFs in early phases of the project, which Spacecraft projects do not, also for Helicopter projects process inclusion has shortcomings.

5.5.2 Step 5: Inclusion of Structure of Helicopter projects

Compared to Spacecraft projects, Helicopter projects do not only stand out in including SHFs in process. They also take much more measures for an inclusive structure. Following the theory, the projects can contribute to this in six ways. The Helicopter's structural inclusion measures are explained below.

<u>Legal/policy infrastructure</u>

Regarding shaping the legal or policy infrastructure for gene-edited crops, about half of the Helicopter projects abstained from influencing regulations in developing countries, similar to Spacecraft projects (Interview 1,4,5,13,15,19,20). Interviewees for example abstained from lobbying because this is very expensive (interview 4), not very effective (interview 4) or because developing countries should decide themselves about their regulations (interview 13).

However, way more often than Spacecraft projects, Helicopter projects did try to influence regulation. Seven out of thirteen Helicopter projects take measures for this (Interview 2,3,8,11,14,21,22,23). Mostly these efforts consist of visiting institutions and informing them about gene-editing. For example, projects speak to governments of Vietnam (interview 22), Ethiopia (interview 14) and Kenya (Interview 21). Others speak to regional organisations like the ASEAN (Association of Southeast Asian Nations) (Interview 22) and the FAO (Food and Agriculture Organisation) (Interview 11). Helicopter projects thus engage with regulatory bodies of developing countries, mostly by providing information. As explained before, this is important to prevent a ban or high regulatory burden (Schmidt et al., 2020). These efforts aim to ensure that gene-editing can reach markets in developing countries and benefit the poor SHFs, showing a pro-poor approach.

Fairness and equalizing measures are though lacking. The same as Spacecraft projects, Helicopter projects for example do not try influence policy to change horizontal inequalities, neither lobby for structural changes that could reduce vertical inequalities.

<u>Institutional infrastructure</u>

Regarding a beneficial institutional infrastructure, similar to Spacecraft projects, Helicopter projects lack inclusion measures. One exception is a project that formed a research consortium, but they focus on only one disease in rice. Possibly in the future they could develop more crops and traits relevant for SHFs, which could perhaps lead to pro-poor benefits. Aside from this exception, further institutional infrastructure building is not present. Pro-poor, equalizing, fairness inclusion is thus not achieved.

<u>Human infrastructure</u>

Contrary to Spacecraft projects whose human infrastructure activities were concentrated in developed countries, 9 of the 13 Helicopter projects are contributing to the human infrastructure in developing countries specifically. This is done in two ways. Firstly, by training students and researchers from developing countries in developed countries (Interview 1,2,3,8,9,13,17,21,23). For example, in a short student program on gene-editing techniques: ”*We embed the graduate student with our scientist to learn transformation and gene-editing. So they spend 10 weeks here. We take care of them the best we can and teach them everything we know*” (Interview 9). Besides, one project financially supports African students to study at European or American universities (Interview 13).

Secondly, by giving trainings, workshops, lectures or seminars in developing countries (Interview 1,2,3,4,7,13,18,19,21). Interviewee 2 does this in Kenya: “*So specifically in Kenya, we're aiming to train scientists there as well. We've already had a couple […] half day events where we basically led seminars with Q&A's afterwards.*” Other Helicopter projects aim to set up such activities in the near future (Interview 11,12,14). Helicopter projects thus contribute to human infrastructure in developing countries in various ways. In a direct way, this could structurally change where gene-edited research is executed: in poor countries compared to previously in rich countries. Thereby this entails an equalizing approach.

Besides direct equalizing effects, this could indirectly lead to pro-poor effects. Interviewee 13 explains that training scientists from developing countries can cause that they subsequently work with gene-editing themselves: "*If you train them well, they can really establish and try to launch their own programs, their own research*" (Interview 13). This exemplifies the effect that building human infrastructure in developing countries can have. According to this interviewee, researchers in developing countries will likely work on SHF relevant crops, he explains: "*So those guys in Africa, they know where to put their focus. They know that only the cultivars used by local farmers are important*" (Interview 13). Literature confirms this; capacity building in developing countries is crucial for availability and accessibility of biotechnologies in these countries (Cohen et al., 2004). This can thereby indirectly lead to pro-poor benefits, as by human capacity in developing countries, more SHF relevant varieties could be developed. Equalizing and, though indirectly, pro-poor approaches are thus present. A fairness approach is absent; none of the projects for example train historically disadvantaged groups such as women.

<u>Financial infrastructure</u>

For financial infrastructure, similar to Spacecraft projects, Helicopter projects do not take inclusion measures. Merely one project, a private company, gives grants to researchers, such as to work on the orphan crop teff (Interview 9). This is a pro-poor approach of financing research on crops relevant for the poor: SHFs. Most project actors are however themselves reliant on funds and thus cannot fund other research. One project mentioned an innovative way of funding; crowdfunding (Interview 17). Other projects could also use crowdfunding to fund research on SHF relevant crops and traits. These two projects are exceptions, other inclusion measures are absent. For financial infrastructure, pro-poor, fairness and equalizing inclusion is thus not achieved.

<u>Technological infrastructure</u>

For technological infrastructure, Helicopter projects again take more inclusion measures than Spacecraft projects. Similarly, the projects share knowledge with other researchers in developed counties (Interview 3,4,8,12,14,17,23), for example in network events or conferences (Interview 1,9,12,13,14). Projects also share genes, varieties and vectors with other researchers (Interview 1,17,23). However, much more often than Spacecraft projects, Helicopter projects engage with researchers in developing countries, such as by organising or attending conferences (Interview 1,3,4,13,18,21). Helicopter projects thereby contribute to the gene-editing capacity in developing countries. Again, this could change socio-economic structures (equalizing) and indirectly could generate more improved crops for SHFs (pro-poor).

Regarding IPR, similar to Spacecraft projects, Helicopter projects also either do not patent their technology (Interview 1,2,3,7,13) or will not enforce their patent for developing country applications (Interview 4,5,9,12,17,22,23). As explained for Spacecraft projects, this shows an equalizing approach, which is however limited as more profound equalizing efforts of changing the IPR structure are not made. Overall, with the project's measures, patents will unlikely prevent researchers for using the project's methodology in developing crops for SHFs.

Public support

Regarding public support, Helicopter projects take additional measures on top of Spacecraft projects' measures. Similarly, Helicopter projects give talks (Interview 1,3,12,18,19,22,23) and use the media (Interview 1,9,12,13,17,19,22), such as by speaking with journalists, news agencies or writing blogs. On top of this, Helicopter projects have public informing activities in developing countries specifically, which Spacecrafts do not. This is done by interviewees based in developing countries (Interview 4,7,18,19,21). A project on cacao explains their activities in Ivory Coast: "*Every year is national cacao and chocolate day with a lot of exhibitions. We give interviews, we receive media.*" (Interview 19). This shows that in the developing country, the project is increasing attention for gene-editing. As in this country the crop will be grown, public acceptance is imperative. Previously, awareness through media has shown to increase the acceptance of GM cowpea in Sub-Saharan Africa (Kushwaha et al., 2004). The public support activities of Helicopter projects in developing countries are thereby very relevant for acceptance.

Exceptionally, one Helicopter project aims for public support by speaking with NGOs (Interview 13). This is not done by any Spacecraft project. Again, a lesson can be learned from GMOs. A wide range of socially trusted NGOs from Europe and North America successfully campaigned for a ban on GMO foods (Paarlberg, 2014). For gene-edited crops to not follow the same route, NGO acceptance is thus important. Interviewee 13 explains that he speaks with NGOs about their anti-technology viewpoint: "*I'm always asking, okay, is this really what the Africans want? Because the Africans I'm talking to, they are rather pro technology".* This shows that this interviewee engages with NGOs in trying to change their opinion and increase acceptance of (bio)technologies.

The taken public support activities can be classified as pro-poor; they aim for public support for gene-editing of pro-poor crops. Similar to Spacecraft projects, Helicopter projects do not take a fairness or equalizing approach in their public support measures.

Summarizing step 5:

Helicopter projects undertake many more measures to build an inclusive structure for gene-editing research compared to Spacecraft projects. They stand out in their activities in human and technology infrastructure, as well as shaping the regulatory system and public support. There is though room for improvement for Helicopter projects as well.

5.5.3 Step 6: Post-structural inclusion of Helicopter projects

Finally, for the highest step of the IIL, Helicopter projects again take more inclusion measures than Spacecraft projects. They do this by 1) including SHF knowledge 2) communicating in SHF languages and terminology, and 3) inclusive goals of their organisations. These three ways and the shortcomings present are explained below.

Firstly, majority of the Helicopter projects incorporate SHF knowledge, contrasting to only one Spacecraft project. 11 out of 13 Helicopter projects acknowledge the importance of SHF knowledge besides scientific knowledge and incorporate SHF knowledge in their projects (Interview 1,2,4,7,9,13,14,17,21,22). For example, Interviewee 1: "*it's more knowledge about what varieties are popular in that country, for example [...], and this is not really published knowledge, this is more informal knowledge that came from talking to farmers.".* This project thus includes SHF knowledge that is non-published. SHF knowledge is also brought in through collaborations, such as a colleague in Nigeria that "*goes and talks to farmers all the time. So, I think yes, it's not just sort of science knowledge that our colleagues can bring."* (Interview 12). This is another way in which SHF knowledge is included. Projects thus use the knowledge of the poor SHFs; considered a pro-poor approach. This is closely related to step 4: process, where Helicopter projects consult SHFs and used this information for project design. Exceptionally, women SHFs are also consulted for information (fairness approach). Overall, Helicopter projects thus include the SHF knowledge and do not only depend on scientific knowledge. The above approach though could be more inclusive, as SHF knowledge is not the main knowledge base. Interviewee 1 explains that "*scientific, published work is, you know, our primary knowledge base",* and interviewee 2 agrees as they *"mostly use scientific knowledge".* Others indicate that SHF knowledge should be more incorporated, to: "*capture better that cultural farmer knowledge that that is needed to succeed at the end of the day"* (Interview 7). These examples show that though SHF knowledge is included in Helicopter projects, this is not done in a structural way whereby all types of knowledge are always considered and used equally. An equalizing approach is thus absent.

Secondly, Helicopter projects go a step further than Spacecraft projects by more often communicating in local languages, next to English. About half of the Helicopter projects use local languages of SHFs in their communications. On the one hand, they do this in conferences, speeches, meetings and interviews (Interview 14,18,19). For example, Interviewee 14 in Ethiopia: "*some of the discussions that have been going on with GMO currently is mainly done in the local language in Amharic and so my discussions have also been in Amharic*". On the other hand, they do this in their contacts with SHFs (Interview 1,3,4,14,18,19). Two projects plan to communicate in SHF languages in later phases (Interview 2,8). Overall, more often than Spacecrafts, Helicopter projects thus communicate in SHF languages.

Besides SHF languages, it is also important to use terminology that is understandable for SHFs. Contrasting to zero Spacecraft projects, two exceptional Helicopter projects do this in their communications with SHFs (Interview 4,14). For example, Interviewee 4 speaks to SHFs "*in their own local language and vernacular, in simple terminology".* Summarizing, by using local language and understandable terminologies, SHFs are more likely to understand the information and be properly informed about the technology. This could increase technology acceptance and thereby be considered pro-poor in benefitting poor SHFs. However, for Helicopter projects communication in all languages and easy terminology is not the standard. This is not embedded in the structure; an equalizing approach is absent. Also, a fairness approach was not found as none of the projects specifically communicate in the language of historically disadvantaged groups, such as ethnic minorities' language.

Thirdly, for majority of Helicopter projects the goals of the organisation they are part of align with the project's goal of creating benefits for SHFs in developing countries. For Spacecraft projects this was the case for half of the projects. For 9 out of 13 Helicopter projects, the organisation focuses on improving agriculture in developing countries specifically (Interview 1,2,3,4,5,7,8,13,18, 19,21,22). The organisation thus also has the goal to provide benefits for the poor; a pro-poor approach. This thereby indicates post-structural inclusion. For example, an interviewee of CGIAR's rice institute IRRI explains: "*This is the type of project that fits IRRI"* (Interview 7). The pro-poor goal of the project to develop improved rice for SHFs in developing countries aligns with the organisation's focus.

Besides pro-poor goals, the organisations of two Helicopter projects articulate fairness goals (Interview 2,7). This was not found among Spacecraft projects. CGIAR institutes CIMMYT on maize and IRRI on rice emphasize socially inclusive research towards women and ethnic minorities (CIMMYT, 2020) and have goals for social equity of women, girls and other marginalised groups (IRRI, 2020). Both these projects are among the exceptions that include fairness approaches on other steps ladder steps. Therefore, the organisation and project align in their fairness approach.

For four projects, the organisation's goal is however not inclusive. Either the organisation focuses both on developing and developed countries (Interview 11,12,17), or the project is more a side activity of the organisation (Interview 9,14,23). For example: *"Many times […] those sort of trait concepts aren't I think probably valuable enough for us to focus on from an organisational standpoint, but it doesn't mean that's not important, it doesn't mean that we can't have a role to play"* (Interview 23). This example shows that developing traits for SHFs is not their main goal. For these four projects, the organisation's goals are thus not inclusive towards SHFs. Inclusion of equalizing goals is also lacking; similar to Spacecraft projects, none of the projects' organisations specifically has goals to change socio-economic structures (equalizing). However, a large majority of the Helicopter's organisations do have, mostly pro-poor, inclusive goals.

Overall, the above shows that, again, Helicopter projects take more inclusion measures than Spacecraft projects. For some aspects, post-structural inclusion is achieved. However, for other aspects post-inclusion is limited or achieved by a few projects only.

6. Comparison Helicopter and Spacecraft projects

The previous chapters explained the way in which inclusion is (not) achieved by Spacecraft and Helicopter projects. Table 4 shows an overview of the results and the similarities and differences between the two models. To be better able to understand the two models that projects follow, the metaphor of Spacecrafts versus Helicopters is explained below.

Table 4: Spacecraft- and Helicopter projects compared

<table>
<tr><th></th><th>Spacecraft projects…</th><th>Helicopter project…</th></tr>
<tr><td rowspan="2">Step 1: Intention</td><td>- Aim to develop an improved crop.</td><td>- Aim to develop an improved crop and build capacity in developing countries.</td></tr>
<tr><td colspan="2">- Focus on widely known issues or issues their developing country collaborator knew about.
- Choose crops and traits based mostly on their food security and economic importance for SHFs, leading to a focus on major crops and diseases.</td></tr>
<tr><td>Step 2: Consumption</td><td colspan="2">- Target SHFs in general. Some projects target women or specific countries.
- Aim to access SHFs by using existing governmental, local company or CGIAR systems.
- Aim for affordability by offering the crops for free or maximum an average market price.</td></tr>
<tr><td rowspan="2">Step 3: Impact</td><td colspan="2">- Aim to improve food security and increase income by improving yields, decrease risks of crops failure and adding value to crops (pro-poor and equalizing impacts).</td></tr>
<tr><td>- Do not aim for fairness impacts.</td><td>- Aim for fairness impacts; benefits for women, children, reduced racial disparity.</td></tr>
<tr><td>Step 4: Process</td><td>- Do not involve SHFs in early phases of their projects, but only plan to interact with SHFs once their crop is finished.</td><td>- Already include SHFs in their process in early phases, either direct or indirect (through partners in developing country). They consult SHFs and use this information in the crop's design. Sometimes they inform SHFs.</td></tr>
<tr><td>Step 5: Structure</td><td>- Are only rarely involved in shaping regulation in developing countries.

- Have activities for public support in developed countries.
- Have measures for human infrastructure and technology transfer, but not for developing countries specifically.</td><td>- Are more often involved in shaping regulation in developing countries, e.g. speaking with governments
- Have activities for public support in developed and developing countries.
- Have measures for human infrastructure and technology transfer for developing countries specifically.</td></tr>
<tr><td>Step 6: Post-structural</td><td>- Very limitedly use SHF knowledge.

- Mostly communicate in English only.
- Organisation's sometimes have inclusive goals.</td><td>- Use SHF knowledge, but this is not seen as the main/most important knowledge.
- Communicate in English, often in local languages, sometimes in easy terminology.
- Organisation's mostly have inclusive goals.</td></tr>
</table>

Projects that only include SHFs in their process (step 4) once the crop is finished are described as Spacecrafts. The Spacecraft gets launched into space where the team works on developing the improved crop. A Spacecraft is far away from the world, which makes communication opportunities limited. This means that the teams are not in contact with their targeted consumers, the SHFs, while developing the crop. This is evident in step 4: process, namely a lack of SHF inclusion in early phases. As Spacecrafts are far away, the teams only see general problems, and thus not include more specific fairness aspects in their research (such as in step 3: impact). As Spacecrafts do not land on earth before the crop is finished, they are not able to build inclusive structures (step 5: structure), such as capacity building in developing countries, let alone shape post-structural inclusion (step 6: post-structure). The projects are thus merely focused on improving a crop (step 1: intention). Once the improved crop is finished, the

Spacecraft will return to earth to test the crop in the field and eventually disseminate it. Spacecrafts are very expensive. Therefore, it is no surprise that all Spacecraft projects, with one exception, are based in developed countries.

Contrary to Spacecraft projects, Helicopter projects already include SHF in their process in early phases (step 4). The projects again work on improving the crops while flying. However, oppositely of Spacecrafts, Helicopters cannot stay in the air too long, they need to land for fuel. Helicopters sometimes land in developing countries, they can even reach rural areas where SHFs live. During landings, the projects speak with SHFs (step 4: process). The information acquired from this is brought back aboard and used in design of the crop. Helicopters are not big enough to actually invite the SHFs on board, so the engagement of SHFs remains limited to consulting and sometimes informing. Flying not too far above land, Helicopters identify the needs of historically disadvantaged groups, resulting in inclusion of fairness aspects in impacts (step 3), process (step 4) and post-structural (step 6). During the landings, Helicopter projects work on building capacity, such as human infrastructure and technology transfer (step 1: intention, step 5: structure), try to shape regulations (step 5: structure), and even take some post-structural measures (step 6). Helicopters are not as expensive as Spacecrafts, thereby project teams located both in developed as well as developing countries can afford them.

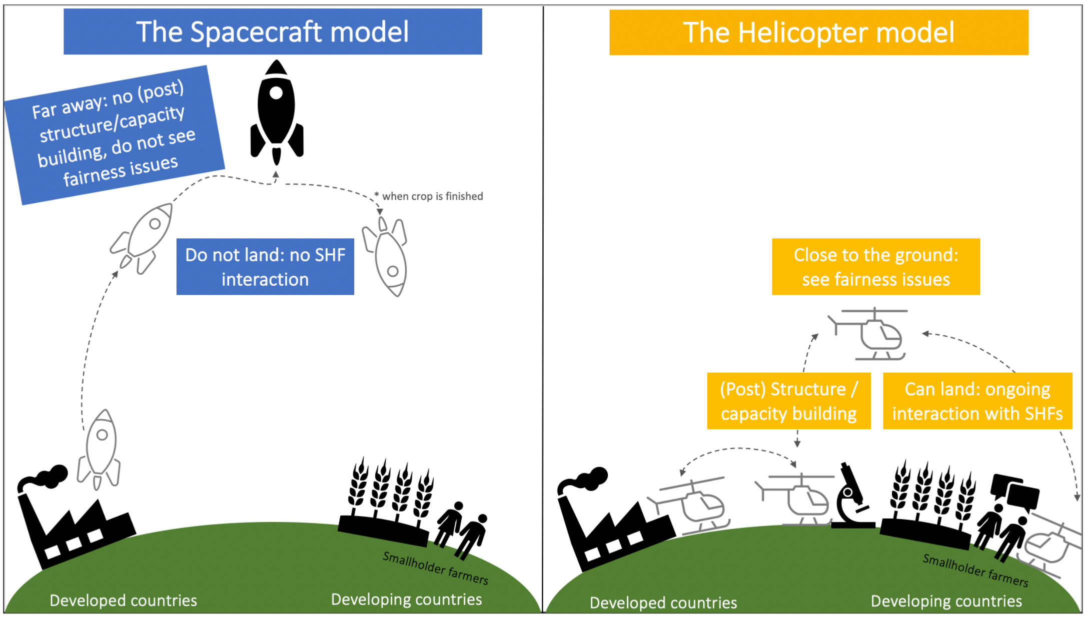

Figure 14: Spacecraft and Helicopter projects visualised

The two metaphors are visualised in Figure 14. It is evident that Helicopter projects have more inclusion aspects than Spacecraft projects; such as more inclusion in step 4- 6 of the IIL, as well as they address more distributive justice approaches. Though Helicopter projects are thus more inclusive, the results also describe their shortcomings in achieving full inclusion. A desired approach could be metaphorically described as a bus driving around in developing countries. The development of the crop is done on this bus. SHFs can board the bus, to actively collaborate from beginning of the project (step 1: intention). They can even easily drive the bus themselves (controlling; step 4: process). While always being on the ground, bus projects can take more measures for structural and post-structural inclusion (step 5 and 6). Such a "bus model" can thereby be more inclusive than the Spacecraft and Helicopter model. In the latter two, for some aspects full inclusion is or will likely not be achieved. This leads to the conclusion of how inclusive the analysed gene-edited projects are, discussed in the next chapter.

7. Conclusion

The about 650 million people in developing countries that are undernourished today will face even increasing challenges for food security and poverty in the future due to climate change and population growth. It is claimed that new gene-editing technologies could contribute to overcoming food insecurity and poverty in developing countries by improving crops. However, this claim has not been tested. This research therefore analysed the potential of gene-editing to deliver inclusive innovations in the agriculture sector. Specifically, it looked at gene-editing of crops and their inclusion of SHFs in developing countries. I contributed to inclusive innovation literature by combining it with theory on normative viewpoints in a comprehensive theoretical framework. This framework combined the six steps of the inclusive innovation ladder (IIL) of Heeks et al. (2013), with the three approaches for distributive justice of Cozzens (2008). This theoretical framework guided answering the following research question:

How inclusive are gene-editing research projects of crops for smallholder farmers in developing countries?

This research question was answered by an embedded case study using a qualitative, deductive research design. Research projects on SHF relevant crops that specifically intend to benefit SHFs were interviewed. In total 18 projects were studied by conducting 23 semi-structured interviews. Analysing these interviews using the theoretical framework led to two main conclusions.

Firstly, gene-editing realised the promise to include SHFs only to a certain extent. We see this from the small number of projects that were found (30) compared to the extensive gene-editing research in general, as well as from how the projects only limitedly fulfil inclusion in all steps of the ladder and for the three distributive justice approaches. Secondly, gene-editing projects take different approaches towards inclusion. I found two models, for which I used the metaphors Spacecraft and Helicopter. Spacecraft projects develop their crops far away from earth and do not interact with SHFs until their crop is finished. Helicopter projects on the contrary fly close to the ground and land in developing countries to speak with SHFs. Figure 15 shows the inclusion measures of both models in the theoretical framework.

For step 1-3 of the IIL, Spacecraft and Helicopter projects have similar approaches. In step 1: intention, projects choose crops and traits mainly based on food security and economic importance, leading to a focus on major diseases in major cash and staple crops. Exceptionally, also less cultivated varieties are being improved, for example orphan crops teff, sorghum and millet. Mostly, despite their potential relevance, less cultivated varieties or less known issues are not included. Besides, the projects do not engage with SHFs when deciding on their focus. Thereby it is uncertain whether most relevant crops and traits are being developed. Regarding consumption (step 2), projects take several steps to ensure this: targeting SHFs, using existing systems of governments, local companies and CGIAR institutes, and offering the crops for maximum average market prices. However, inaccessibility and unaffordability are likely to remain barriers for certain SHFs, especially those not reached by existing systems, as well as the poorest- and women SHFs. Concerning impact (step 3), most projects aim for increasing income and ensuring food security; pro-poor and equalizing impacts. The limited focus on fairness creates uncertainty whether disadvantaged groups will benefit from gene-edited crops. For step 1-3, the projects thus have inclusion measures, but these also have shortcomings.

	Pro-poor		Fairness		Equalizing	
	Spacecraft	Helicopter	Spacecraft	Helicopter	Spacecraft	Helicopter
6: Post-structural	Not found	Use SHF knowledge Communication in local language + easy terminology (2 projects)	Not found	Use knowledge of women SHFs (1 project) Organisation's goal: benefit women and ethnic minorities (2 projects)	Not found	
	Organisations goal: benefit the poor (2 projects)	Organisation's goal: benefit the poor (majority)				
5: Structure	Public support in developed countries	Public support in developing countries	Not found	Not found	No IPR/IPR not enforced in developing countries	
	Not found	Lobby for beneficial regulation			Not found	Capacity building in developing countries
4: Process	Not found	Include SHFs in design: ensuring suitable crops	Not found	(plan to) Include women (2 projects)	Extra income for SHFs by collaboration and dissemination (2 projects)	Extra income for SHFs by collaboration (4 projects)
3: Impact	Increasing income, improving food security, improving quality of life		Not found	Overcome racial disparity, positive impact for women, reduce child labour (5 projects)	Increasing income and education for SHF children; changing socio-economic structures	
2: Consumption	Targeting the poor: SHFs. Access through existing governmental, local companies and CGIAR systems. Affordable by free-average market price.		Affordable for women: free (4 projects)		Targeting low-income group: SHFs Affordable for the poorest: free (4 projects)	
			Not found	Targeting women SHFs (1 project)	Not found	Improving seed systems (2 projects)
1: Intention	Choosing crops and traits based on food security and economic importance for SHFs. Focussing on known SHF issues.		Not found		Choosing crops based on economic importance for developing countries	
					Not found	Capacity building

Figure 15: Results summarised in the Theoretical framework

For the highest three steps of the ladder, Spacecraft and Helicopter projects show rather different inclusion approaches. Helicopter projects have more inclusion measures, however also for these projects there is room for improvement. In step 4: process, Helicopter projects include SHFs by consulting them in early phases and using this information in the crops' design. On the contrary, Spacecraft projects only plan to engage with SHFs once their crop is finished. Neither Helicopter nor Spacecraft projects include SHFs in invention, (plan to) empower SHFs or let SHFs control the project. Inclusion thereby remains limited. Regarding structural inclusion (step 5): Helicopter projects show several inclusion measures such as building human capacity in and enabling technology transfer to developing countries, which Spacecrafts did not. This is closely related to the intention (step 1) of Helicopter projects to build capacity. However, both Spacecraft and Helicopter projects lack inclusion measures for improving the financial and institutional infrastructure, as well as fairness approaches. In the last step of the ladder, step 6, Helicopter projects again take more inclusion measures than Spacecraft projects. For example, by communicating in the local language of SHFs and integrating SHF knowledge in their projects. However, full inclusion was in this step not achieved by either of the models, for example as including all types of knowledges was not the standard. Concluding; Helicopter projects are more inclusive than Spacecraft projects, but neither models achieved full inclusion of SHFs on all steps.

Besides the difference on the steps of the IIL, the two models also differ in inclusion according to the three distributive justice approaches. Both Helicopter and Spacecraft projects include pro-poor and equalizing aspects on various steps on the ladder. However, Helicopter projects more often have equalizing measures, such as their capacity building goals. Helicopter projects are also the only projects that included fairness aspects on multiple steps of the ladder. They do this by focusing on impact for women, children and decreasing racial disparity (step 3), specifically targeting women SHFs (step 2), (planning too) include women SHFs in the process (step 4) and being part of an organisation with fairness goals (step 6). Spacecraft projects do not include such fairness aspects.

The above reveals that projects with more inclusion measures in step 4: process (Helicopter projects), are more inclusive compared to projects without process inclusion (Spacecraft projects). By saying this, I do not refer to inclusion in this step only. This conclusion is built on the correlation found between inclusion in step 4 and inclusion in other aspects, namely higher on the IIL (step 5 and 6), as well as for wider distributive justice approaches (fairness). An important finding of this study is thereby that inclusion in process (step 4) is critical for achieving inclusive innovation.

Together, these findings are relevant in several ways. First, they show that while gene-editing *can* indeed be used for SHFs, as promised, inclusion is only achieved to a limited extent. Action needs to be taken to realise its potential. Second, the results give directions for what additional inclusion measures the research projects should take. Though Helicopter projects are more inclusive than Spacecraft projects, full inclusion is not achieved; inclusion can be improved in every step of the ladder, as well as for the distributive justice approaches. Recommendations for this are given in the discussion section. Third, theoretically, the novel comprehensive approach of combining the ILL with distributive justice theory proved worthwhile. In the next section I will elaborate on how this helped with identifying limits to inclusion that would not have been found when the results were only analysed using the IIL.

8. Discussion

8.1 Reflection on the results and literature

This research found that projects on gene-editing crops for SHFs are only inclusive to a certain extent. It is relevant to compare this finding to literature on inclusion of GM. As explained in the introduction, gene-editing is claimed to have potential to be more inclusive towards the poor compared to GM. For GM claims of benefitting developing countries were also made (Buechle, 2001), but argued not to be realised (Biddle, 2017; Fischer et al., 2015). Though for gene-editing the realised benefits cannot be assessed yet, as SHFs are not growing the crops, we can reflect on the inclusion measures taken to ensure these benefits. Firstly, gene-editing projects seem more diverse than GM, which is mostly focusing on maize, soybean, cotton and canola, entailing 99% of GMO sales (ISAAA, 2017). Though for GM also more diverse crops might have been targeted in research, the GMO market is rather narrow. Contrastingly, gene-editing research includes crops only relevant for SHFs, such as cassava, tef, and pearl millet. Rice is the most researched variety in gene-editing, which was not dominant for GM. The gene-editing crop range is thus more diverse compared to GM, however, many orphan crops are not included in gene-editing projects either. Gene-editing is still rather concentrated on major cash and staple crops. Secondly, a literature review unveils that GMOs were often unaffordable and inaccessible for SHFs (Fischer et al., 2015). It is unsure whether this will not be the case with gene-edited crops. Though projects have some inclusion measures planned for this (step 2: consumption), it remains uncertain whether affordability and accessibility issues will be overcome for all SHFs. This indicates that gene-editing is rather similar to GM.

Based on these two examples a change in inclusiveness in gene-editing projects seems necessary for the gene-edited crops to bring more benefits to SHF than GM. Firstly, gene-editing should be applied to a diverse range of crops that are most suitable for SHFs, and for which improvements are most needed (step 1: Intention). Projects could conduct and/or analyse SHF surveys on challenges in (orphan) crop cultivation. Another way to identify SHF challenges is by working together with local NGOs or local farmer organisations that speak with SHFs regularly. Ideally, projects should directly involve SHFs (representatives) when choosing which crops and traits to focus on. Secondly, to overcome inaccessibility (step 2), instead of using existing systems of governments, local companies and CGIAR institutes for dissemination, projects could rely on informal systems. An estimated 90% of SHFs access seeds through informal seed systems (McGuire & Sperling, 2016). Thirdly, to overcome affordability issues (step 2) for SHFs with limited resources (the poorest, women), relying on public funding might not suffice. Projects could partner with private organisations, charities or NGOs to ensure that for these groups, the crops can be offered for free or a real affordable price. By adopting these inclusion measures, the chances will increase that gene-editing delivers more inclusive innovations towards SHFs compared to GM.

Besides comparing gene-editing to GM, it is useful to reflect on the results using other studies on gene-editing. One of the main findings of this research is that inclusion in process (step 4) correlates with other aspects of inclusion. Several other studies also argue for the importance of inclusion in process, such as the engagement of the broader public, beyond experts, in gene-editing (e.g. Burall, 2018; Jasanoff et al., 2015; Wirz et al., 2020). However, this research is unique in providing a comprehensive understanding on how inclusion in process can be achieved for gene-edited crops specifically. Others explained that it is important to provide information to SHFs about gene-edited crops (Van Tassel et al., 2020) or to be more transparent and educate local communities to ensure acceptance of CRISPR crops in Sub Saharan Africa (Ogaugwu et al., 2019). Similarly, I found that indeed informing and educating are important, though would not suffice as "inclusive". According to my findings, for full inclusion in process, projects should engage SHFs from the first moment and SHFs should control decision making. On top of that, SHFs should be involved in ensuring suitable crops are developed (pro-poor), historically disadvantaged groups are included in the process (fairness) and SHFs should be able to, for example, choose over for example ownership and distribution of benefits (equalizing). Overall; other scholars have thus identified the need for SHF inclusion in process as an important aspect in gene-editing as well but are less comprehensive in this.

Based on my comprehensive results, projects are recommended to increase inclusion in process (step 4) in several ways. Researchers in developed countries can collaborate with (research) organisations in developing countries that are already in contact with SHFs and can facilitate SHF engagement. If projects take a capacity building approach, tight collaborations with partners in developing countries can be set up. Capacity building is thereby an intermediate factor to achieve process inclusion. Furthermore, process inclusion should not only consist of consulting SHFs but take shape of collaborating with them, empowering them or ultimately let SHFs control the project. SHF representatives could for example be included in the governance of projects and provide input in meetings in the form of an advisory board. However, more profound inclusion would be achieved when SHFs are actually part of the project lead, participate in meetings and can influence decisions. For the inclusion moment, projects should engage SHFs before the project starts. Furthermore, it is recommended to include historically disadvantaged groups such as ethnic minorities and women SHFs in the process. As inclusion in process correlated with other inclusion aspects, it is expected that following these recommendations could increase overall inclusion.

Besides reflecting on the results, it is important to reflect upon the theories used in this research. As explained in the theory section, the IIL is accumulative in nature. However, not many empirical examples exist that support this hypothesis for high steps of the ladder (Heeks et al., 2013). This hypothesis is however confirmed by my research, which indeed showed that steps high up the ladder were only achieved when those lower on the ladders were (to a certain extent) inclusive too. For this I refer back to the Helicopter versus Spacecraft model, whereby the projects with more inclusion in step 4 (Helicopters), also showed more inclusion in step 5 and 6. This thereby confirms that the ladder is accumulative in nature in higher steps as well.

In this light, it also not surprising that projects with limited inclusion measures in step 4, also have limited inclusion in step 5 and 6 (Spacecraft projects). This further backs up the recommendation for gene-editing projects to ensure inclusion in step 4 (discussed in previous paragraph), as well as it calls for strengthening inclusion in lower steps. Namely, the accumulative nature of the IIL entails that for achieving inclusion in the highest steps, the steps below need to be inclusive to start with. For step 1 and 2 recommendations are discussed in the comparison to GM. For step 3 impact: projects should pay more attention to historically disadvantaged groups such as women and ethnic minorities. It is recommended to work together with NGOs or other organisations specialised in this, for example initiatives as the fellowship "African Women in Agricultural Research and Development" that aims for more gender-responsive production and dissemination of agricultural R&D (AWARD, 2020). Another option is for projects to dedicate part of their budget to ensuring impacts for historically disadvantaged groups. Due to the confirmed accumulative nature of the IIL, it is recommended for projects to follow the recommendations in lower steps first, before aiming for inclusion in higher steps.

When inclusion in lower steps is achieved, projects could aim for inclusion in step 5 and subsequently 6. For step 5: structure, projects are amongst others recommended to again include fairness aspects, as none of the projects included fairness in their structure building measures. Projects could for example start programs for training women researchers (human infrastructure) or form collaborations to support gene-editing crops to benefit ethnic minorities (institutional infrastructure). For step 6: post-structural inclusion from an equalizing approach would mean that the projects' structure is changed so all types of knowledge and all languages, also those of low-income groups, are always included in the research. For example, standard procedures could be set up that ensure this, and language editors can be hired for translations. These are examples on how on the highest steps of the IIL inclusion could, eventually, be improved.

For the theoretical framework, the IIL was combined with the three distributive justice approaches. This was helpful in identifying different approaches to inclusion at various steps of the ladder. Specifically, using distributive justice theory I found that not all distributive justice approaches are applied equally by the projects. Projects mostly follow a pro-poor approach, and least often a fairness approach. This is in line with earlier literature by Cozzens (2010), who hypothesized that pro-poor approaches are most often observed in developing countries, and fairness approaches are less likely to be found. The dominance of pro-poor approaches could also be explained by the fact that the projects were selected based on their potential and intention to benefit SHFs in developing countries with their crops. This may favour pro-poor approaches, even though fairness approaches would have been perfectly possible, for example by focusing on female SHFs or SHFs of minority groups. In literature it was also described that an innovation can be considered as inclusive from the perspective of several distributive justice approaches at the same time (Cozzens, 2010). This is what I, to some extent, also found in this research; projects mainly take a pro-poor approach, but this is sometimes combined with equalizing- and more limitedly with fairness measures.

The distributive justice theory proved to be helpful in identifying limits to inclusion that would not have been found when the results were only analysed using the IIL. For example, if only the IIL would have been used in a "checkbox" approach, the impact box (step 3) would have been checked as the projects aim to create impact for SHFs. However, when analysing impact using the three distributive justice approaches, it became clear that impact will unlikely be created for historically disadvantaged groups. The projects mostly aim for pro-poor and equalizing impacts. The fairness approach is only exceptionally included in the project's impact. Without analysing the results with a distributive justice lens, this would not have been identified. The distributive justice theory thus helped to critically evaluate inclusion of the projects. This shows the relevance of combining both theories, as it led to a framework that is more comprehensive in understanding and assessing inclusion.

Lastly, the comprehensiveness of the theoretical framework proved valuable. Harsh et al. (2018) previously combined the IIL with distributive justice but argue that equalizing and fairness approaches provide more specific understanding of the highest steps of the IIL only, and pro-poor for the lowest steps only. I however drafted and used a comprehensive framework where all distributive justice approaches were sought for in all steps of the IIL. This proved suitable, as I also found equalizing and fairness approaches on lower steps, as well as pro-poor approaches on higher steps. This thus contrasts the hypothesis of Harsh et al. (2018). The comprehensiveness of the framework thus proved valuable for analysing inclusion and adds to the literature field of inclusive innovation.

8.2 Limitations of the research

To evaluate the limitations of this research, first it is important to consider the criteria for research quality. Three important quality criteria for social research are reliability, replicability and validity (Bryman, 2016). Reliability concerns the assurance of when a study is repeated, the same results will be generated (Yin, 2003). In this research reliability is ensured by interviewing 18 projects, which limits the risk that results are largely influenced by an outlier project. Replicability refers to whether other researchers can replicate the study (Bryman, 2016). By providing the criteria for the research projects, search terms, interview guide and coding scheme, replicability of this research is increased. Validity refers to the integrity of the conclusion (Bryman, 2016). Validity in this research is lowered through absence of data triangulation; the interviews are the only data source. Besides, only one researcher conducted the interviews and analysed the results. Though reliability and replicability increase the research quality, validity is a limitation of this study.

Furthermore, limitations are present concerning the set of interviewees. Firstly, the project leader was not always available, therefore in three instances another member of the project was interviewed. These interviewees did possibly not have the same knowledge as the leaders, who are responsible over taking decisions in the project. I also experienced this, as in a few instances these interviewees mentioned that they did not know the answers or had not been involved in that subject. The acquired information for these three projects could thereby be incomplete on a few specific topics.

Secondly, projects were often collaborations between researchers in developed- and developing countries. In two projects the developing country collaborator was not spoken with. Interviews with the collaborator could have given a better insight in for example the SHF contact (step 4: process), as in many projects the collaborator was in charge of this.

Thirdly, the Bill & Melinda Gates Foundation (BMGF) is a funder of many of the interviewed projects. The BMGF was reached out to but did not give an interview. Interviewing the BMGF would have been especially interesting as interviewees indicated that the BMGF was actively involved in their project. For example, they participate in meetings as well as have prerequisites for their funding, such as giving the developed crop for free to the public sector. An interview with the BMGF could have given interesting insights in their vision on inclusion, which influences many projects by funding them. For all three above groups, attempts were made for arranging interviews but this was not always with success. Overall; the set of interviewees is a limitation of this research.

Lastly, this research has limitations as the studied research projects are all in early phases with no product on the market. Therefore, for some aspects the projects were asked about planned measures rather than already taken measures. For example, for step 2: consumption, projects were asked how they will bring the crop to the consumer. Though this gives initial insight in whether inclusion will (not) be achieved, the measures that projects will ultimately take might be different. Asking about plans gives less valid results compared to asking about already occurred occasions, as these are not subject to change. Asking about plans is thus another limitation of this study, though it does provide the earliest insight in inclusion.

8.3 Future research recommendations

Based on the findings of this research, recommendations for future research can be given. Firstly, longer term research is necessary to analyse the actual impact of the above projects. This can be done once the crops are grown and harvested by the SHFs. Future research should focus on whether projects with more inclusion measures also lead to more or different benefits for SHFs. Specifically, it is interesting to research whether inclusion in process (step 4), which was in this research found to correlate with other inclusion aspects, leads to more or different benefits. For this a longitudinal design is necessary, whereby a sample is studied at least twice over a certain period of time (Bryman, 2016).

Secondly, projects that include SHFs in their process (step 4) should be researched more deeply. As the projects indicate to take into account the consulted information of SHFs in their projects, it would be interesting to analyse how this is done. For example, by observing interaction with SHFs, such as their field visits or farmer days, as well as projects meetings in which the acquired information is discussed. Especially how this correlates with inclusion on other aspects should be paid attention to. By this, a more in-depth understanding of the importance of process inclusion in relation to the other steps of the ILL and the distributive justice approaches can be gained.

Thirdly, next to future research on gene-editing projects, it is interesting to regard the wider field that this research is situated in. Agroecology and biotechnology are often seen as opposing pathways towards a sustainable agriculture system and food security (Bonny, 2017; Eastmond & Robert, 1992). Agroecology is explained to be characterised by its farmers participation in the form of collaboration and integration of farmers knowledge in research (Méndez et al., 2013). Contrastingly, this research showed that in gene-editing, farmers participation is, if present at all, mostly limited to consulting, and SHF knowledge is not always integrated. This suggests that there are differences in inclusion between agroecology and gene-editing. A comparative case study on SHF inclusion between an agroecology project and a gene-editing project, for example on the same crop and trait, could be interesting. Analysing how the projects differ on inclusivity could bring insights in how both of them can become more inclusive. This way, gene-editing could learn from another type of agricultural innovation.

Lastly, moving beyond agriculture to a wider field, the developed theoretical framework can be used in various contexts. From this research it became clear that the framework is useful in analysing inclusivity and identifying limited attention to certain distributive justice approaches. In future research, this framework can be used for analysing gene-editing technologies in different industries, such as health, as well as other emerging technologies, such as nanotechnology. By using this comprehensive framework, inclusive innovation research can create more insights in, and build towards, the inclusion of marginalised groups. The benefits for marginalised groups that could be the result of this, could contribute to lowering the inequalities that are evidently present in today's society.

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Appendices

Appendix I: Classification developing countries

It is acknowledged that developing countries might be a problematic term to use; however it is chosen to use this term as it is also used by large international organisations as the United Nations, International Monetary Fund and World Trade Organisation (IMF, 2019; UNCTAD, 2018; WTO, n.d.). As classification of "developing country" appears to be diverging among different bodies (Fialho & Van Bergeijk, 2017), in this research the classification of the World Bank of low income and lower-middle income countries is used (World Bank, 2020). In this research, the countries in Table 1 and 2 are considered as developing countries (based on World Bank, 2020). Lastly, it is important to note that with using one term for grouping countries, it is not assumed that countries can be regarded as similar or should be generalised.

Table 1: Low income countries

Afghanistan	Guinea-Bissau	Sierra Leone
Benin	Haiti	Somalia
Burkina Faso	Korea, Dem. People's Rep.	South Sudan
Burundi	Liberia	Syrian Arab Republic
Central African Republic	Madagascar	Tajikistan
Chad	Malawi	Tanzania
Congo, Dem. Rep	Mali	Togo
Eritrea	Mozambique	Uganda
Ethiopia	Nepal	Yemen, Rep.
Gambia, The	Niger	
Guinea	Rwanda	

Table 2: Low-Middle Income Countries

Angola	Indonesia	Pakistan
Bangladesh	India	Philippines
Bhutan	Kenya	São Tomé and Principe
Bolivia	Kiribati	Senegal
Cabo Verde	Kyrgyz Republic	Solomon Islands
Cambodia	Lao PDR	Sudan
Cameroon	Lesotho	Timor-Leste
Comoros	Mauritania	Tunisia
Congo, Rep.	Micronesia, Fed. Sts.	Ukraine
Côte d'Ivoire	Moldova	Uzbekistan
Djibouti	Mongolia	Vanuatu
Egypt, Arab Rep.	Morocco	Vietnam
El Salvador	Myanmar	West Bank and Gaza
Eswatini	Nicaragua	Zambia
Ghana	Nigeria	Zimbabwe

Appendix II: Total list of crops

In Table 3, the total list of crops is shown, combining the crops of the four lists explained in the Methodology section; Crops to end Hunger CGIAR (CGIAR, 2018), African Orphan Crop Consortium (AOCC) (African Orphan Crops Consortium, n.d.), Scientific review of orphan crops of Tadele (Tadele, 2019) and Sustainable Smallholder Agribusiness programme (SSAB, n.d.).

Table 3: Total list of crops.

Latin name	English name	List
Abelmoshus esculentus/caillei	Okra	AOCC/Tadele
Adansonia digitate	Baobab	AOCC/Tadele
Allanblackia floribunda	Veg tallow tree	AOCC
Allanblackia stulhmanii	Allanblackia	AOCC
Allium cepa	Onion	AOCC
Amaranthus cruentus	Grain amaranth	AOCC
Amaranthus spp.	Amaranth	Tadele
Amaranthus tricolor	Vegetable amaranth	AOCC
Anacardium occidentale	Cashew	AOCC/SSAB
Ananas comosus	Pineapple	SSAB
Annona reticulata	Custard Apple	AOCC
Annona senegalensis	Wild Custard Apple	AOCC
Artocarpus altilis	Breadfruit	AOCC
Artocarpus heterophyllus	Jack Tree	AOCC
Balanites aegyptiaca	Balanites	AOCC
Basella alba	Vine spinach	AOCC
Boscia senegalensis	Aizen, Nabedega	AOCC
Brassica carinata	Ethiopia Mustard	AOCC
Cajanus cajan	Pigeon pea	CGIAR/SSAB/Tadele
Camellia sinensis	Tea	SSAB
Canarium madagascariense	Canarium nut, Ramy nut	AOCC
Capsicum annum L/frutescens L	Chili	SSAB
Carica papaya	Papaya	AOCC
Carissa spinarum	Carissa	AOCC
Casimiroa edulis	White sapote	AOCC
Cassia obtusifolia	Sickle Senna	AOCC
Celosia argentea	Celosia	AOCC
Chenopodium Quinoa	Quinoa	Tadele
Chrysophyllum cainito	Star apple	AOCC
Cicer arientinum	Chickpea	CGIAR/Tadele
Cinnamomum zeylanicum	Cinnamon	SSAB

Citrullus lanatus	Watermelon	AOCC
Cleome gynandra	Spiderplant	AOCC
Cocos nucifera	Coconut	AOCC
Coffea	Coffee	SSAB
Colocasia esculenta	Taro	AOCC/Tadele
Corchorus olitorius	Jute mallow	AOCC
Crassocephalum rubens	Yoruban bologi	AOCC
Crotalaria juncea	Sunn hemp	AOCC
Crotalaria ochroleuca	Rattlebox	AOCC
Cucumis metuliferus	Horned Melon	AOCC
Cucurbita maxima	Pumpkin	AOCC
Cyphomandra betacea	Cape tomato	AOCC
Dacryodes edulis	African Plum	AOCC
Detarium senegalense/microcarpum	Sweet detar	AOCC
Digitaria exilis	Fonio	AOCC/Tadele
Dioscorea alata	Yams	AOCC
Dioscorea dumetorum	Bitter yam	AOCC
Dioscorea rotundata	Yams	AOCC
Dioscorea spp	Yam	CGIAR/Tadele
Diospyros mespiliformis	African persimmon	AOCC
Dovyalis caffra	Kei Apple	AOCC
Elaeis guineensis	Oil palm	SSAB
Eleusine coracana	Finger Millet	AOCC
Ensete ventirocosum	Enset	AOCC/Tadele
Eragrostis tef	Tef	AOCC/Tadele
Fagopyrum Escelentum	Buckwheat	Tadele
Faidherbia albida	Acacia (Apple-ring)	AOCC
Garcinia livingstonii	African Mangosteen	AOCC
Garcinia mangostana	Mangosteen	AOCC
Glycine max	Soybean (Sub Saharan Africa only)	CGIAR/SSAB
Gnetum africanum	African Gnetum	AOCC
Gossypium	Cotton	SSAB
Guizotia abyssinica	Noug	Tadele
Hevea brasiliensis	Rubber	SSAB
Hibiscus sabdariffa	Roselle	AOCC
Hordeum vulgare	Barley	CGIAR/SSAB/Tadele
Icacina oliviformis	False yam	AOCC

Ipomoea batatas	Sweet potato	CGIAR/Tadele
Ipomoea batatas	Sweet Potato Leaves	AOCC
Irvingia gabonensis	Sweet bush mango	AOCC
Lablab purpureus	Lab lab Bean	AOCC
Landolphia spp	Gumvines	AOCC
Lannea microcarpa	Tree grapes	AOCC
Lathyrus Sativus	Grass pea	Tadele
Lens culinaris	Lentil	AOCC/CGIAR/Tadele
Linum unitatissimum	Linseed	Tadele
Macadamia ternifolia	Macadamia	AOCC/SSAB
Macrotyloma geocarpum	Geocarpa groundnut	AOCC
Macrotyloma uniflorum	Horsegram	Tadele
Mangifera indica	Mango	AOCC/SSAB
Manihot esculentum	Cassava	CGIAR/SSAB/Tadele
Momordica charantia	Bittergourd	AOCC
Moringa oleifera	Drumstick tree,	AOCC
Moringa oleifera	Moringa	Tadele
Morus alba	Mulberry	AOCC
Musa spp.	Banana	AOCC/CGIAR/Tadele
Musa spp.	Plantain	CGIAR
Olea europaea	Olive (oil)	SSAB
Opuntia monacantha	Prickly pear	AOCC
Oryza sativa	Rice	CGIAR/SSAB
Orzya glaberrima	African rice	Tadele
Panicum miliaceum	Millet	CGIAR/Tadele
Parinari curatellifolia	Mobola plum	AOCC
Parkia biglobosa	African Locust	AOCC
Passiflora edulis	Passion Fruit	AOCC
Persea americana	Avocado	AOCC/SSAB
Phaseolus	Beans	CGIAR/SSAB
Phaseolus vulgaris	Green Bean	AOCC
Pisum	Pulses (other)	CGIAR
Plectranthus esculentus/rontundifolius	African Potato	AOCC
Psidium guajava	Guava	AOCC
Ricinodendron heudelotii	Groundnut	AOCC/CGIAR/SSAB
Rinicus communis	Castor bean	Tadele
Saba comorensis	Rubber vines	AOCC

Saba senegalensis	Nsaban, kabaa	AOCC
Sclerocarya birrea	Marula	AOCC
Sesamum indicum	Sesame	SSAB/Tadele
Solanum aethiopicum	African Eggplant	AOCC
Solanum lycopersicum	Tomato	SSAB
Solanum scabrum	African Nightshade	AOCC
Solanum tuberosum	Potato	CGIAR/SSAB
Sorghum bicolor	Sorghum	CGIAR
Sphenostylis stenocarpa	Yambean	AOCC
Strychnos cocculoides	Natal orange	AOCC
Strychnos spinosa	African Orange	AOCC
Syzygium guineense	Water berry	AOCC
Talinum fruticosum	Ceylon spinach	AOCC
Tamarindus indica	Tamarind	AOCC
Telfairia occidentalis	Fluted gourd	AOCC
Theobroma cacao	Cocoa	SSAB
Triticum	Wheat	CGIAR/SSAB
Tylosema esculentum	Marama bean	AOCC
Uapaca kirkiana	Wild loquat	AOCC
Vangueria madagascariensis/infausta	African Medlars	AOCC
Vanilla Planifolia.	Vanilla	SSAb
various names	Pulses (aggregate)	CGIAR
Vicia faba	Favabean	AOCC
Vigna radiata	Mungbean	AOCC
Vigna subterranean	Bambara groundnut	AOCC/Tadele
Vigna unguiculata	Cowpea	CGIAR/Tadele
Vitellaria paradoxa	Shea Butter	AOCC
Vitex doniana	Chocolate berries	AOCC
Xanthosoma sagittifolium	Elephant ears	AOCC
Xanthosoma spp	Cocoyams, Arrowroots	AOCC
Ximenia caffra	Sour plum	AOCC
Zea mays	Maize	CGIAR/SSAB
Ziziphus mauritiana	Jujube	AOCC

Appendix III: Interview Guide

Introduction:

Thank you for making time for this interview! First a short introduction from my side. As I wrote in my email, this interview is for my master thesis. I am researching gene-editing of crops to see how this can benefit smallholder farmers in developing countries. For this I am interviewing several actors of research projects that are developing crops that aim to benefit smallholder farmers.

- Is it okay if I record this interview?
- Can I use your name and/or project name in my thesis? Or do you prefer to stay anonymous?

Introductory questions:

- Could you tell me something about yourself and your job?
- Have you worked with gene-editing or genetic modification technologies in the past?
- What do you think gene-editing can mean for SHFs in developing countries (in general!)?

General project questions

- Could you tell me something about the gene-editing project?
- What is the aim of the project?
- What is your role in the project? – Since when have you been involved?

Step 1) Intention

- How did the research project start, how was the idea generated?
- What was the motivation behind it? - How was the need/problem identified?
- How was the crop chosen? And the trait?
    - Considering poverty/historically disadvantaged groups/the socio-economic structure?
- What is the goal of the project? And what about wider goals, such as societal goals? For example, reducing vertical/horizontal inequality?

Step 2) Consumption

- Who is your target group? (the poor/historically disadvantaged groups/low-income)
- Who will be the customers of the seeds of your crop?
- How will you bring your crop to your customers?
- How will you ensure consumption in dev. countries & by SHFs?
- How will you overcome affordability and accessibility challenges?
    - Especially, for the poor, historically disadvantaged groups, for low-income groups?

Step 3) Impact

- What impact will your crop have? In developing countries specific? On poverty? For historically disadvantaged groups? For the socio-economic structure?
- If only answered increased yields/income; what about the wider impact?

<u>Step 4) Process</u>
- Who are involved in the project and since when have they been involved?
- Other stakeholders involved? For each stakeholder; how are they involved?
- In specific: are SHFs involved? And women/ethnic minorities/historically disadvantaged groups?
  - In what way do you (plan to) involve them?
  - Where in the innovation process do you (plan to) involve them?
- Who finances the project? How is the financer involved?

<u>Step 5) Structure:</u>
- Does your team also address <u>broader aspects</u> of how gene-editing benefits developing countries?
  - Are you/is your team involved in shaping policy or lobbying for beneficial legal conditions, policy and regulation? If yes; how?
  - Are you/is your team involved in founding an organisation to support gene-editing of crops? e.g. NGO or research collaboration. If yes; how?
  - Are you/is your team involved in training or educating others on gene-editing skills? If yes; how?
  - Are you/is your team improving access to financial resources/funding for gene-editing? If yes; how?
  - Are you/is your team involved in activities that transfer your technology to others? If yes; how?
  - Intellectual property rights; did you/are planning to file a patent? Why (not)?
  - Are you/is your team involved in other activities that could ensure public support for gene-editing of crops? If yes; how?

<u>Step 6) Post-structural</u>
- What do you consider as the most important type of knowledge? What are other relevant types of knowledge? (How) are they included?
- In what languages is information about your project available?
- In what technical language is information about your project available?
- Beyond your project, for your wider organisation/research group; what is the goal/mission?

<u>Is there anything else about project you would like to add?</u>

<u>Reflection</u>
- Do you think gene-editing has potential to bring benefits to SHFs in general? What constrains this potential?
- Is your work representative for gene-editing research in general?
- If you were the president of the world, what would be the first thing you would change to ensure gene-editing benefits SHFs?

<u>End:</u>
- Snowballing: do you know any other gene editing projects that aim to benefit SHFs?

That were all my questions for now! Do you have any questions? Would you like to receive the final version of my thesis? Thank you very much!

Appendix IV: Coding framework

IIL step	Sub-category	Pro-poor	Fairness	Equalizing
Step 1: Intention	Goal setting – crop (how crops are selected)	Projects choose crops based on their potential to benefit the poor	Projects choose crops based on their potential to benefit historically disadvantaged groups	Projects choose crops based on their potential to change socio-economic structures and reduce vertical inequality
	Goal setting – trait (how traits are selected)	Projects choose traits based on their potential to benefit the poor	Projects choose traits based on their potential to benefit historically disadvantaged groups	Projects choose traits based on their potential to change socio-economic structures and reduce vertical inequality
	Intentions beyond improving trait of a crop	Other intentions could lead to more benefits for the poor	Other intentions could lead to benefitting historically disadvantaged groups	Other intentions could lead to changing socio-economic structures and reduce vertical inequality

IIL step	Sub-category	Pro-poor	Fairness	Equalizing
Step 2: Consumption	Targeted consumer	The project targets the poor as consumers	The project targets historically disadvantaged groups as consumers	The targeted consumer group can lead to changed socio-economic structures and reduced vertical inequality
	Accessibility (how the crops will be made accessible for SHFs; dissemination)	The project ensures accessibility for the poor	The project ensures accessibility for historically disadvantaged groups	The project takes structural measures to ensure accessibility for low-income groups
	Affordability (how the crops will be made affordable for SHFs)	The project ensures affordability for the poor	The project ensures affordability for historically disadvantaged groups	The project takes structural measures to ensure affordability for low-income groups

IIL step	Description	Pro-poor	Fairness	Equalizing
Step 3: Impact	Prospected or intended impact	The project reduces poverty or alleviates the conditions of poverty	The project creates benefits for historically disadvantaged groups	The project changes the socio-economic structure in a way that reduces vertical inequality

IIL step	Description	Pro-poor	Fairness	Equalizing
Step 4: Process	Moment of SHF inclusion (ranging from invention to distribution)	The moment of inclusion of SHFs creates pro-poor benefits	The moment of inclusion of historically disadvantaged SHFs reduces horizontal inequalities	The moment of inclusion of SHFs changes socio-economic structures and thereby reduces vertical inequality
	Type of SHF inclusion (ranging from informing to controlling)	The type of inclusion of SHFs creates pro-poor benefits.	The type of inclusion of historically disadvantaged SHFs reduces horizontal inequalities	The type of inclusion of SHFs changes socio-economic structures and reduces vertical inequality

IIL step	Description	Pro-poor	Fairness	Equalizing
Step 5: Structure	Legal/policy infrastructure (regulations and policies for innovation)	Projects contribute to a legal/policy infrastructure that supports gene-edited crops to reach the poor (SHFs)	Projects contribute to a legal/policy infrastructure that supports inclusion of historically disadvantaged groups	Projects contribute to a legal/policy infrastructure that changes the socio-economic structure in a way that reduces vertical inequality
	Institutional infrastructure (collaborative structures and organisations that support inclusive innovation)	Projects contribute to the establishment of an institution that aims to support gene-editing for pro-poor purposes	Projects contribute to the establishment of an institution that aims to support gene-editing for or by historically disadvantaged groups	Projects contribute to the establishment of an institution that aims to change socio-economic structures and thereby lower vertical inequality
	Human infrastructure (human knowledge and skills of gene-editing)	Projects engage in human capacity building that could lead to that more pro-poor benefits are created	Projects engage in human capacity building of historically disadvantaged groups that could reduce horizontal inequalities	Projects engage in human capacity building that could change socio-economic structures and thereby vertical inequalities

	Financial infrastructure (accessible capital for R&D, for financing the crops itself is tackled at step 2)	Projects contribute to accessible capital for R&D for pro-poor gene-edited crops	Projects contribute to accessible capital for R&D for gene-editing crops for or by historically disadvantaged groups	Projects contribute to accessible capital for gene-editing which changes socio-economic structures and reduces vertical inequality
	Technological infrastructure (diffusion and availability of gene-editing technology)	Projects contribute to a gene-editing technological infrastructure that could lead to more pro-poor benefits being created	Projects contribute to a gene-editing technological infrastructure that reduces horizontal inequalities	Projects contribute to changing the gene-editing technological infrastructure in a structural way that reduces vertical inequality
	Public support (public support for the innovation)	Projects contribute to public support for crop gene-editing for the poor	Projects contribute to public support for crop gene-editing for and by historically disadvantaged group	Projects contribute to public support for gene-editing to change socio-economic structures and reduce vertical inequality

IIL step	Description	Pro-poor	Fairness	Equalizing
Step 6: Post-structural	Knowledge (the knowledge included in the project)	Knowledge of the poor is included in the project	Knowledge of historically disadvantaged groups is included in the project	The project is structured in a way that different types of knowledge, including those of low-income groups, are always included
	Language (the language used in the project's communication)	The poor understand the language used in communication of the project	Historically disadvantaged groups understand the language used in communication of the project	The project is structured in a way that different types of languages, including those of low-income groups, are always used in communication
	Organisation's goal (the goal of the organisation of the project's actors)	Organisation's goal is to benefit the poor	Organisation's goal is to benefit historically disadvantaged groups and thereby reduce horizontal inequalities	Organisation's goal is to change socio-economic structures and thereby reduce vertical inequality