The labour implications of genome editing in crops:

How experts foresee jobs to be affected resulting from these revolutionary technologies

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Abstract

Introduction: Genome editing technologies such as CRISPR/Cas9, TALENs, and ZFN, are considered as revolutionary for plant breeding practices. These far-reaching technologies have been addressed in literature, which focused on multiple environmental and societal implications. However, this research did not mention the labour implications of genome editing, despite indications that genome editing could have future impact on jobs. This thesis aims to answer the following research question: *What labour implications do experts expect to occur due to crop genome editing?* Experts' expectations were identified, as genome editing is still in an early phase of development and their specific expertise was essential to explore the potential labour implications in the future.

Theory: This study investigates how genome editing affects jobs according to the multi-sectoral framework of Vermeulen et al. (2018). This framework considers the importance of how technology affects tasks. Certain tasks are created due to technological innovation, leading to new or transformed jobs, whereas substituted tasks lead to jobs becoming obsolete. Also, this framework addresses the differences in labour implications per employment sector. Additionally, I investigated if the expected labour effects are happening in developed or developing countries.

Methodology: To study the expected labour effects, semi-structured interviews with 33 experts from both developed and developing countries were held. Two types of experts were interviewed: genome editing experts and labour experts.

Results: I found that genome editing is expected to affect many types of jobs worldwide. It is foreseen that it will create new jobs, transform existing jobs, and make certain jobs obsolete. These effects differ per sector. In the sector where the technology and genome edited crops are developed, jobs are expected to be mostly newly created. In the sectors that grow, and process genome edited crops, jobs are mostly foreseen to be substituted. Last, in the sectors that are complementary to the development of genome editing, like the legal and academic sector, jobs are mostly expected to transform. These effects are seen in developed as well as developing countries.

Discussion: The findings show that genome editing can have both positive and negative effects for employment. To mitigate the negative effects, strategies should be created that focus on reinstating labourers that are substituted by genome editing and ensuring that workers are allocated to newly created and transformed jobs. Finally, this research shows that labour implications should be considered when discussing potential pathways for governing these far-reaching technologies.

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1. Introduction

In October 2020, Emmanuelle Charpentier and Jennifer Doudna received the Nobel Prize in Chemistry for their discovery of CRISPR/Cas9: a tool to rewrite the code of life (The Royal Swedish Academy of Sciences, 2020). CRISPR/Cas9 enables one to reveal and alter the genetic code of every organism with unprecedented precision, speed and cost-effectiveness (Chen et al., 2019). Possible modifications are activating or inactivating a gene depending on whether its function is desired, repairing a malfunctioning gene, or inserting foreign gene sequences into the genetic code to add genetic functions (Ricroch, 2019). This method is not the first genome editing tool. Others, like TALENS and ZFN, have been around for about 25 years (Georges & Ray, 2017). However, CRISPR is even more precise, user-friendly, and cheaper (Haque et al., 2018; Xiong et al., 2015).

The discovery of CRISPR/Cas9 showed how far-reaching the possibilities of genome editing technologies are. With regard to the performance improvement of crops, which is the subject of this thesis, the technologies are seen as revolutionary (Georges & Ray, 2017). Genome edited crops are expected to significantly increase agricultural yields. Hence, they form part of the solution to overcome the mounting challenge of food security. Moreover, genome edited crops could be more beneficial for the environment as they are seen to restore balance to the stressed agricultural system (Hartley et al., 2016; Ricroch, 2019).

Besides the opportunities that genome editing technologies offer, there are risks too. Thus far, research on the societal implications of genome editing has predominantly focused on five different concerns. First, the environmental risks have been addressed thoroughly, stressing the possibility of disturbances of ecosystems (Araki et al., 2014; Furrow, 2017; Wolt, 2017). Second, researchers focused on the potential risk of genome editing to the health of humans and animals, pointing at potential off-target effects that might have detrimental consequences (Furrow, 2017; Lassoued et al., 2019; Steinbrecher, 2015). Third, research addressed concerns related to the governance of genome editing technologies and stressed that current regulatory frameworks are not sufficient (Bartkowski et al., 2018; Hartley et al., 2016; Jasanoff et al., 2015). Fourth, economic implications have been addressed, pointing at the concerns that the economic benefits due to yield increases may be unequally distributed between large biotech companies and small farmers (Baltes et al., 2017; Furrow, 2017; Jasanoff et al., 2015; Ricroch, 2019). Last, several authors stressed ethical considerations and discussed if genome editing can be considered morally right. This discussion was based on whether the technologies maximize happiness for all affected individuals and if the technology can be considered 'natural'. Both are determinants assessing if the technology is considered 'right' (Bartkowski et al., 2018; Gregorowius et al., 2012; van Haperen et al., 2012).

Despite the various environmental and societal implications discussed, research has not addressed the labour implications of genome editing technologies. Labour implications of a technology refer to its effect on employment dynamics: will jobs be created or lost (Calvino & Virgillito, 2018)? The labour implications of other technological innovations, such as automation (Acemoglu & Restrepo, 2018; Vermeulen et al., 2018) and digitalization (Dachs, 2018; Goos, 2018) have been extensively addressed in research. These examples show that technologies can have significant effects on jobs by affecting tasks performed by workers. Specific tasks are taken over by the technology, leading to the jobs that carry out these tasks becoming obsolete. On the other hand, technology also creates demand for new and complementary tasks, resulting in a transformation of a job or newly created occupations (Acemoglu & Restrepo, 2018).

Research showed that technological innovation generally leads to a net increase in employment, as the number of created jobs is more significant than that of jobs that became obsolete (Acemoglu & Restrepo, 2018; Autor, 2015). However, there are significant differences in implications per employment sector, country, and type of job. For example, the demand for labour often increases in sectors that develop the technology, whereas in sectors that utilize the technology the demand for labour decreases (Dosi et al., 2021; Vermeulen et al., 2018; Vivarelli, 2015). Additionally, jobs in developing countries are seen to be hit harder by technology induced substitution than jobs in developed countries. Furthermore, jobs that consist highly of routinized tasks are prone to becoming obsolete as these tasks are codifiable and can easily be taken over by the technology. (Autor, 2015; Goos, 2018).

For genome editing, no research has been conducted that identifies how these technologies affect labour. However, there are indications that genome editing will bring about labour implications. For example, Xu (2016) argues that genome editing can be used to regulate the architecture of an apple tree in a way that mechanized harvesting is enabled. The genes that regulate the tree's height and shape can be unveiled and modified. As a result, a shorter tree with a homogenous canopy can be designed, which would make it easier for machines to pick the apples. Because of the mechanized harvesting, fewer agricultural labourers are likely needed on the field. This example indicates a potential labour implication of genome editing. However, we generally lack knowledge about the effects that genome editing can have on jobs. Therefore, in this thesis, I examine the following research question:

What labour implications do experts expect to occur due to crop genome editing?

To answer this research question, I identified what experts in the field expect to happen. Interviews with 33 experts were conducted to achieve this thesis' aim. Two types of experts were interviewed: scientists with expertise in the field of genome editing in crops and scientists researching labour effects of other technologies within the agricultural sector.

The research question is answered using a task-based framework of categorizing job effects across multiple sectors developed by Vermeulen et al. (2018). It is used because it stresses the importance of the innovation's effect on tasks and how this affects jobs. Moreover, this framework looks at labour implications per sector, which is essential to account for as literature shows that labour implications vary per sector (Dachs, 2018; Vermeulen et al., 2018; Vivarelli, 2015). I complimented this framework by including if the affected job is situated in a developed or developing country, since this is seen to influence which jobs are influenced by the technology (Vivarelli, 2014).

This study contributes to the academic research on the implications of genome editing technologies by identifying and systematically studying an important societal implication of genome editing that is hitherto unknown. This is important, as their full range of implications has not been sorted out yet (Furrow, 2017). Furthermore, most technological innovations that were found to have significant labour implications, such as automation and digitalization, were studied ex post. This research focuses on mapping labour implications of a technology that is in an early stage of development and is not widely adopted, nor is there empirical data available. By adopting an ex-ante approach, this study contributes to the underdeveloped field of studying future labour implications of impactful technologies.

This research is relevant to society, because by identifying the labour implications of crop genome editing, I contribute to a more complete assessment of the spectrum of societal implications of genome editing technologies. Thereby, a better-informed debate on how to govern such revolutionary technologies can be achieved. Moreover, given previous technologies' trajectories, genome editing could enhance labour inequalities (Dachs, 2018). By assessing what the effects on jobs will be, and what type of jobs in which sectors and countries are likely to be affected, initial steps can be taken towards tackling this inequality. Based on the findings of this study, further research could focus on fitting policy measures.

2. Literature review

To understand the labour implications of genome editing technologies, it is essential to understand first what genome editing technologies are. Moreover, many issues regarding genome editing in crops have been raised. These environmental and social implications will be discussed.

2.1 Genome editing in a nutshell

Genome editing is a revolutionary way of improving the characteristics, which are often called 'traits', of a crop by editing its genetic code. One could, for example, improve a crop's resistance to a pathogen or improve its yield. Genome editing technologies allow for alterations of genes of organisms with unprecedented precision, speed, and effectiveness (Chen et al., 2019; Xiong et al., 2015). By using these technologies, you can target a specific DNA sequence within a genome responsible for the crop's genetic function. Subsequently, precise, and predictable modifications at that specific piece of the DNA code are made. These modifications might concern activating, repressing, or inserting certain genetic functions (Bortesi & Fischer, 2015; Chen et al., 2019; Xiong et al., 2015). Various genome editing technologies such as ZFN and TALENs have been discovered, but one in particular has been hailed as highly promising: CRISPR/Cas. Compared to the former technologies, CRISPR/Cas is dramatically cheaper and more effective (Xiong et al., 2015). Because of the technical and economic advantages of genome editing technologies in general and CRISPR in specific, they are considered technologies that could tackle food security issues and improve agricultural systems (Georges & Ray, 2017; Hartley et al., 2016).

2.2 Environmental and societal implications of crop genome editing

Besides the vast amount of opportunities, scholars identified certain risks associated with genome editing, including in the field of agriculture (Baltimore et al., 2015). The literature on the effects of genome editing technology addressed five types of implications. These are environmental, health, governance, economic, and ethical implications. A handful of studies also addressed other topics, such as consumer perception (Bartkowski et al., 2018; Ishii & Araki, 2016). However, the majority of research focused on the former five areas. Studies on these areas brought forward positive and negative implications, which will be addressed in this order.

First, literature addressed the environmental implications of genome editing technologies. Scholars emphasize the increased ability of crops to cope with biotic and abiotic stress which secures the yield (Baltes et al., 2017; Chen et al., 2019; Ricroch, 2019). Furthermore, genome edited crops require fewer resources and improve soil health, resulting in a decreased burden on the stressed agricultural systems (French, 2019; Hartley et al., 2016). However, multiple authors argue that once genome edited crops are released to the environment, they could form a threat to biodiversity as they may destabilize ecosystems (Araki et al., 2014; Eckerstorfer et al., 2019; Lassoued et al., 2019; Ricroch, 2019). This interference is hard to identify, because appearance-wise, genome edited crops are very similar to conventionally bred crops. Also, the genome edited DNA of the crop is passed on to offspring, especially in the case of so-called 'gene drives', which are changes in the DNA that results in offspring inheriting the modifications. Therefore, scholars have expressed the concern that once the crop is exposed to the environment, the disturbances are strenuous, if not impossible, to reverse (Araki et al., 2014; Furrow, 2017; Wolt, 2017).

Second, a societal implication brought up in research relates to genome editing and its health effects (Baltes et al., 2017; COGEM, 2019; Ricroch & Hénard-Damave, 2016). Research showed that genome editing technologies could improve the quality of food in terms of higher nutritional value and a decreased presence anti-nutritional or even potentially dangerous compounds (COGEM, 2019; Ricroch & Hénard-Damave, 2016). Examples are fruits with increased antioxidants that accumulate nutritional value (Baltes et al., 2017). However, despite the precision that genome editing is praised for, much is still unknown regarding the potential risk for human health (Lassoued et al., 2019). Furrow (2017) points at the existence of off-target effects: a modification to non-targeted DNA that can cause unwanted effects. These effects could for example be an accumulation of toxins, or an increase in allergens, threatening the health of humans and animals (Steinbrecher, 2015).

The third implication that scholars have thoroughly assessed is the governance implications of genome editing technologies. (Bartkowski et al., 2018; Furrow, 2017; Hartley et al., 2016; Jasanoff et al., 2015; Lassoued et al., 2019; Ricroch & Hénard-Damave, 2016).This research focuses on assessing effective and responsible structures for the governing of genome editing. These structures determine the players that will develop the technology, who will control the seed and food market, and which agricultural systems will prevail (Hartley et al., 2016). Scholars argue that the governance structure is shaped by the regulatory framework that is in place (Furrow, 2017; Jasanoff et al., 2015). Previous biotechnologies, such as genetically modified organisms (GMOs), were strictly regulated. This resulted in only large agricultural companies having the financial resources to develop the technology (Ricroch & Hénard-Damave, 2016). Many scholars argue that by developing fitting regulations that do not impede the technology but instead regulate genome editing on a case-specific basis, smaller players are also allowed to access the market. Because of the decreased legal costs, the cost effectiveness and ease of using the technology, it becomes cheaper to develop crops that could make it to the marketplace. This might allow for a decentralized power structure. A governance climate can be created that does not favour large biotech companies, but allows smaller players to practice their governing power too (Bartkowski et al., 2018). However, many countries, such as all countries within the European Union, prohibit the use of crop genome editing. This might lead to a similar governance climate as prevailed with GMOs (Lassoued et al., 2019).

The fourth implication research focused on relates to the economic implications of genome editing technologies in crops. Several authors pointed out that the commercialization of genome edited crops would lead to economic benefits for farmers as their yields are likely to be increased and/or secured (Baltes et al., 2017; Ishii & Araki, 2016; Ricroch, 2019). Conversely, others argue that leaving genome editing technologies to the market is not likely to lead to the most significant economic benefits (Bartkowski et al., 2018; Helliwell et al., 2017; Jasanoff et al., 2015). Corporate interest could control the food chain leading large corporations to expand their economic benefits at the expense of smaller players.

Last, the ethical implications regarding genome editing in crops have been extensively studied (Bartkowski et al., 2018; Gregorowius et al., 2012; Nordberg et al., 2018; van Haperen et al., 2012). This research discusses the morality of crop genome editing. The morality of the technology is assessed from two perspectives: the utilitarian perspective and the deontological perspective. From a utilitarian perspective, genome editing is considered morally right if it maximizes happiness for the individuals that are affected by the technology (Bartkowski et al., 2018; Gregorowius et al., 2012). From a deontological perspective, technology is morally right if it complies with society's normative principles. For genome editing, 'naturalness' is often mentioned as a normative principle, which refers to the assumption that nature is always good. Hence, genome editing is considered good if it is 'natural' (Bartkowski et al., 2018). In addition, genome editing is seen as a potential solution to secure food supply, which is a utilitarian argument brought up in favour of the technology's rightness (Bartkowski et al., 2018; Furrow, 2017). From a deontological standpoint, genome editing could be considered natural as it is not necessary to insert any foreign DNA into the crop (Bartkowski et al., 2018; van Haperen et al., 2012). Therefore, you can create mutations that could be achieved in nature too, but significantly faster (Georges & Ray, 2017). However, there are still many uncertainties regarding off-target effects on society and the environment, which is often mentioned to counter the utilitarian argument. These off-target effects can have detrimental effects that should be included to assess if genome editing actually maximizes happiness (Gregorowius et al., 2012). There are also arguments countering the deontological understanding of genome editing being natural. Some argue that any human interference in the evolution of a crop violates nature's path and is thus unnatural and immoral (Bartkowski et al., 2018; van Haperen et al., 2012).

There has thus been extensive research on genome editing and the implications that the technologies have on the environment and society. The five implications mentioned above (environmental, health, governance, economic, and ethical implications) received much attention and many scholars have thoroughly assessed the benefits and disbenefits of genome editing based on these five themes. However, the labour implications of genome editing are not mentioned once in any research on the implications of the technologies. This is remarkable, as there are indications that genome editing will affect jobs. In the introduction, I discussed the example of apple trees and labourers involved in apple picking that could be affected by the introduction of a genome edited tree. Therefore, to uncover the full range of implications of genome editing technologies, its effect on labour should thus be investigated. Furthermore, the effect on jobs of other far-reaching technologies such as automation and digitalization has been extensively researched (e.g., Acemoglu & Restrepo, 2019; Dachs, 2018; Goos, 2018; Vivarelli, 2015). It showed that technologies could have substantial effect on jobs across several sectors and countries.

2.3 Labour implications

To identify if and how genome editing technologies affect labour, it is necessary to assess the labour implications of other technological innovations. This relationship between technology and labour has been extensively researched. It is shown that there are significant differences in the effect that technological innovation has on jobs depending on the sector, country, and job type (Autor, 2015; Vermeulen et al., 2018; Vivarelli, 2015). I will discuss these factors in the following section. Furthermore, to explain how a job is affected, research tells that it is necessary to assess how a job's tasks are affected (Acemoglu & Autor, 2010). The role that these tasks have in the identification of the labour implications of technological innovation is explained. The factors that cause variation in labour implications of technological innovation and the importance of tasks to explain how jobs are affected are combined in the framework developed by Vermeulen et al. (2018) that categorizes labour implications of technological innovation. I use this framework to study the labour implications of genome editing and I will elaborate on this framework in the part of this section.

2.3.1 General labour implications of technological innovation

This research is unique in terms of the focal technology: genome editing. However, a plethora of earlier research focused on technological (un)employment due to other technological innovations intelligence (Acemoglu & Restrepo, 2018; Dachs, 2018; Ernst et al., 2019; Korinek & Stiglitz, 2017; Vermeulen et al., 2018). Recently, this research has mainly centred on three particular technological innovations: automation (Acemoglu & Restrepo, 2018; Dachs, 2018; Vermeulen et al., 2018), digitalization (Dachs, 2018; Goos, 2018), and artificial intelligence (Acemoglu & Restrepo, 2018; Ernst et al., 2019; Korinek & Stiglitz, 2017). In addition, this academic work focuses on how innovation affects employment dynamics, meaning if it is beneficial or detrimental for the employment level.

Research argues that technological innovation threatens jobs in cases where it has a comparative advantage over the worker (Vivarelli, 2015). The main reason why technology has an advantage over human labour is because it causes the production process to be more efficient: it produces the same output with fewer production factors. Production factors are either labour or capital. Labour refers to work performed by workers. Capital is referred to as goods to produce other goods, such as machinery, equipment, or technology (Hodgson, 2014). Because of the focus of this thesis, from now on I will refer to 'technology' instead of 'capital' when addressing the substitute for human labour. Research shows that because the technology does the same job as the worker, but is more productive. The result is that fewer workers are needed in the production process (Calvino & Virgillito, 2018; Dachs, 2018; Vivarelli, 2015). Therefore, a direct labour-saving effect is induced when technological innovation takes over human labour.

Research identified that technological innovation does not only lead to a cut in jobs. It generally leads to a higher demand for jobs that are complementary to the innovation, and to new jobs that emerge because of the innovation (Acemoglu & Restrepo, 2018, 2019; Autor, 2015; Dachs, 2018; Vivarelli, 2015). This effect thus presses against the initial labour-saving effect that technological innovation might have. Empirical analysis shows that technological innovation makes certain jobs obsolete, but more jobs are created overall, making it labour-friendly (Autor, 2015; Dachs, 2018; Vivarelli, 2015).

However, the complex reality behind the employment dynamics is neglected if only the eventual net rise in employment level is considered. Instead, certain factors should be considered that determine the variance in labour implications.

2.3.2 Factors causing variation in labour implications

Research identified that the labour implications of a technological innovation vary significantly per employment sector, development level of a country, and job type (Autor, 2015; Cirera & Sabetti, 2019; Dachs, 2018; Dosi et al., 2021; Vermeulen et al., 2018; Vivarelli, 2014, 2015)

The labour implications of technological innovation differ per employment sector. Four types of sectors are identified to experience labour dynamics differently (Vermeulen et al., 2018; Vivarelli, 2015). Empirical analysis shows that only one type of sector copes with a net decrease in employment level induced by a substitution effect of the technological innovation (Dachs, 2018; Vermeulen et al., 2018). This is the sector that employs the technological innovation and will be referred to as the 'applying' sector. This contrasts with the demand for labour in the high-tech sectors that develop the technological innovation, which I will refer to as the 'making' sector. Here the demand for workers rises more than the number of jobs substituted (Dachs, 2018; Dosi et al., 2021; Vermeulen et al., 2018; Vivarelli, 2015). In Vermeulen et al. (2018) two additional types of sectors are identified in which the demand for labour increases due to technological innovation: the complementary and quaternary sectors. Complementary sectors are those that facilitate or inhibit the uptake of the technological innovation, such as the educational, consultancy, and regulatory sector. Quaternary sectors produce goods that are non-essential to consumers, such as leisure, travel, and culture. They argue that technological innovation will result in a higher disposable income in the making and complementary sectors. This income will be spent in quaternary sectors, resulting in an increasing demand for labour there.

The labour implications per sector that are described above are based on research done with a focus on developed countries, which has been the predominant focus of academics (Acemoglu & Restrepo, 2018; Autor, 2015; Dachs, 2018; Vermeulen et al., 2018). However, Vivarelli (2014) identifies that the labour implications of technological innovations differ depending on the level of development of a country. Labour implications in developing countries are different from those in developed ones, as a less developed making sector generally characterizes them. Therefore, technologies are often imported instead of being developed within the country, resulting in few employment opportunities being realized in the developing sector in the developing country. Moreover, because of the low labour costs in developing countries, they have an extensive applying sector. The jobs in the applying sector are generally seen as labour-intensive occupations. We saw that jobs in the applying sector are in general more susceptible for substitution. Therefore, if an innovation is imported from a developed country, the developing country's employment level is seen to be hit more negatively (Artuc et al., 2019; Cirera & Sabetti, 2019; Vivarelli, 2014). Some researchers suggest that technology leads to decreased costs of the production process which results in an increased demand for the end-product. This could lead to a higher demand for jobs in this sector, which might countervail the job destruction effect of the innovation (Cirera & Sabetti, 2019; Ernst et al., 2019). This, however, is partly contradicted by other scholars who suggest that technological innovation can also decrease the costs of a production process to the extent that companies decide to move back operations concerned with applying the innovation to their home country (Artuc et al., 2019; Carbonero et al., 2018; UNCTAD, 2016). Research did not specify the labour effects of technological innovation in the complementary or quaternary sectors in developing countries (Artuc et al., 2019; Cirera & Sabetti, 2019; Ernst et al., 2019; Vivarelli, 2014). Therefore, only differences within the making sectors and applying sectors can be highlighted.

Furthermore, academics have been extensively debating which type of jobs are susceptible to become obsolete, and which type of jobs are expected to rise in demand (Autor, 2015; Goos et al., 2014; Goos & Manning, 2007). It has been assumed that the extent to which a job is prone to be substituted by technology depends on how skilled the worker is. Research argued that unskilled workers are more susceptible to be replaced by technology than highly skilled workers (Vivarelli, 2015). The overall productivity of the production process will be augmented more if unskilled workers are replaced by technology rather than skilled workers. However, recent scientific work points out that this categorization is not nuanced enough Autor, 2015; Dachs, 2018; Goos, 2018; Goos & Manning, 2007). It is found that the extent to which a job is routinized determines if it is more susceptible to be overtaken by technology. This is referred to as routine-biased technological change.

To assess the extent to which a job is routinized, one should look at the individual tasks that the worker performs. Some tasks are routine based, while others are not, regardless of the skill level needed to perform them. Research tells that technology generally substitutes the routinized tasks that are easily codifiable (Acemoglu & Autor, 2010; Acemoglu & Restrepo, 2019; Autor, 2015; Goos, 2018). When someone has a job that consists of highly routinized tasks, there is a higher chance that his or her job will become obsolete. In contrast to the idea that skills determine which occupations rise in demand, routine-biased technological change increases demand for jobs carrying out 'abstract' and 'manual' tasks, which are both non-routine tasks. Abstract tasks are often found in technical and managerial positions and generally require inductive reasoning, communication skills and a high level of technical expertise. The people carrying out abstract tasks are highly skilled and have well developed analytical capabilities (Autor, 2015). Manual tasks are tasks that require situational adaptability and in-person interaction and are often found in occupations that require workers to be physically adept. Examples of such occupations are waiters, hairdressers, security guards and caretakers. The people carrying out manual tasks are generally lowly skilled (Autor, 2015). Workers carrying out abstract as well as those carrying out manual tasks are not likely to be substituted by technology, as both types of tasks are hardly codifiable. Contrarily, middle-skilled workers are employed in jobs with a greater extent of routine tasks, such as administrative workers and salespersons. These jobs are more prone to become obsolete, as technology takes over these tasks codifiable tasks (Acemoglu & Autor, 2010; Acemoglu & Restrepo, 2019; Autor, 2015; Goos, 2018).

This results in what is called 'job polarization': the increasing demand for workers carrying out abstract and manual tasks, while workers with occupations consisting of routinized tasks are substituted (Autor, 2015; Goos et al., 2014; Goos & Manning, 2007). However, despite the demand for both types of tasks increasing, job polarization only results in the income of workers carrying out abstract tasks to rise. This is because their tasks often require specific technical knowledge or specific skills that cannot be performed by workers previously carrying out routine tasks, because they do not possess the skills needed. Therefore, these middle-skilled workers started filling in low-skilled occupations when their previous job became obsolete. This results in an increase in labour supply for occupations carrying out manual tasks, and hence a lower wage. Therefore, if not tackled by policies that reorchestrate the labour market accordingly, job polarization generally results in inequality between workers carrying out manual and routinized tasks and those performing abstract tasks (Autor, 2015; Goos, 2018).

To assess which jobs are highly routinized and which are not, it is thus essential to look at the tasks performed by the worker. The range of tasks of a job determines how that job will be impacted. Therefore, I will elaborate more on the importance of tasks.

2.3.3 The role of tasks

To assess the impact of a technological innovation has on jobs, research identifies that it is necessary to assess how an innovation affects tasks. In section 2.3.1 I discussed the initial labour-saving effect of technological innovation. I also discussed that the same innovation leads to a rise in demand for existing jobs and the emergence of new jobs. Research describes these effects in more detail by looking at how the tasks of a job are impacted.

First, the initial labour-saving effect has been extensively described by means of assessing the technological innovation's impact on tasks losses (Acemoglu & Restrepo, 2018; Autor, 2015). To produce something, certain tasks need to be performed. This can be achieved either by labour or by technology. Technological innovation leads to technology taking over certain tasks previously performed by labour, because it can do them more efficient. When it takes over a significant part of the tasks formerly performed by the worker, a strong displacement effect occurs that leads to job losses (Acemoglu & Restrepo, 2018).

Second, research also identifies that the demand for labour increases for those tasks that are either complementary to the technology, or necessary to exploit the benefits of it (Acemoglu & Restrepo, 2018, 2019; Autor, 2015). Thereby, technological innovation leads to job creation too, as it increases the demand for tasks where labour has a comparative advantage over capital. Acemoglu and Restrepo (2018, 2019) explain that technological innovation leads to certain tasks in the production process that are taken over, but many tasks are still necessary to be performed by the worker. Because of the decreased cost per unit the end-product becomes cheaper. This leads to a higher demand for these products and subsequently an increased demand for those tasks that have not been displaced by the technology. Furthermore, research emphasizes that those tasks concerned with developing and improving the technology increase in demand as well (Acemoglu & Restrepo, 2018, 2019). Scholars point out another effect that presses against the displacement of tasks, which is the creation of new ones (Acemoglu & Restrepo, 2018, 2019; Autor, 2015). These are tasks that emerge because of the technological innovation. The emergence of new tasks can lead to a transformation of existing occupations to complement the technology (Acemoglu & Restrepo, 2018, 2019). An example of a transformed job is the job of the bank teller. Due to the introduction of the ATM, the tasks performed by bank tellers became substantially different. Bank tellers' tasks became focused on providing customer services and sales rather than handling cash (Autor, 2015). Newly created tasks can also lead to an entirely new type of job that emerges because of the technological innovation. Software programming, for example, is a job that was not existing before the rise of computer technology. These new tasks are the most powerful force pressing against the labour-saving effect of a technology (Acemoglu & Restrepo, 2018, 2019).

The effect that technological innovation has on tasks thus determine how a job will be affected. If a worker performs many routinized tasks that can be taken over by technology, his or her job will be substituted. This substitution effect is offset by those tasks that are not taken over by the technology, which will increase demand. Furthermore, new tasks can emerge as well, which results in transformed jobs or newly created ones. The aggregated effect a technology has on tasks thus determines the eventual labour implications, that is, which jobs will become lost, which will remain or transform, and which jobs will be newly created.

2.3.4 Multisectoral framework

Previous research has studied the labour implications of technological innovation almost exclusively ex post (Acemoglu & Autor, 2010; Acemoglu & Restrepo, 2019; Autor, 2015; Dachs, 2018; Goos & Manning, 2007). This thesis, however, aims at projecting labour implications of a technological innovation that is at an early stage of development. Therefore, to study these effects ex-ante, the framework of Vermeulen et al. (2018) is adopted (Figure 1).

	'Making' sectors (Producing & developing, supplying & supporting)	**Applying sectors**	**Complementary sectors (Inhibiting & facilitating)**	**Spillover sectors (E.g. quaternary)**
Existing occupations	+ Increase in demand for technology + Increase in demand for upstream capital goods + Deepening automation	- Displacement + Increase in demand due to lower prices due to increase of productivity	- For old technology, largely automated occupations	+ Increase in employment and disposable income in 'making' & complementary sectors - Decrease in employment and disposable income in applying & complementary sectors
Exploiting & transforming occupations		+ Exploitation of complementarities in form of new tasks or even (specialized) jobs	+ For new technology, occupations transforming and reaping complementarities	+ Increase in employment and disposable income for higher skilled workers in applying sectors
Emerging occupations	+ Entrepreneurial and innovation activities + New high skilled and high paid jobs, notably for accumulation of technological development	+ Resources freed up put to use in creating new products/ services + New applications + New occupations due to new ways of organizing, communication, new social processes, etc.	+ For new occupations and new technology	+ Increase in employment and disposable income in newly created occupations in 'making' sectors

Figure 1: Expected labour implications due to the introduction of the focal technology per sector, adopted from Vermeulen et al. (2018).

This framework offers a structure for identifying the labour implications of crop genome editing. It is adopted because it centralizes the importance of tasks. To identify which and how jobs will be affected, it is essential to look at tasks specifically. The authors argue that technological innovation's effect on tasks can lead to four different outcomes on jobs: a job can become obsolete, it can remain the same, it can transform, or a new job can emerge. A more in-depth explanation of job outcome can be found in Table 1.

Additionally, the framework by Vermeulen et al. (2018) is adopted is because the authors account for the variance in labour implications per sector. The authors adopt a multi-sectoral approach. They argue that when studying labour implications of a technology, the focus should not lie solely on one sector, as the effects often span different ones. They identify four sectors and state that jobs can become obsolete, remain, transform, or emerge in each sector. The sectors they distinguish are the making sector, the applying sector, the complementary sector, and the quaternary sector. In Table 2 a more detailed explanation per sector is given.

Table 1: The impact on jobs due to technological innovation (Vermeulen et al., 2018)[1].

Impact on jobs	Description
Substituted jobs	These are the occupations that are substituted due to genome editing technologies displacing their tasks.
Transformed jobs	These are the occupations that will transform to reap the complementarities of genome editing. New tasks are added to the existing range of tasks and certain existing tasks are substituted to complement genome editing technologies.
Remaining jobs	These are the occupations that remain the same in terms of tasks. They increase in demand due to the introduction of genome editing technologies, which assumingly leads to a reduction of costs per unit, followed by a rise in demand.
New jobs	These are occupations that emerge because of new tasks that are focused on using, extending, or recombining genome editing technologies. Thus, the new occupations reap the opportunities of genome editing technologies.

Table 2: The sector types affected by the innovation (Vermeulen et al., 2018).

Sector	Description
Making sector	This sector consists of occupations concerned with developing the genome edited crops. These are the scientists that design, for example, the genetic structure of rice in such a way that the crops are drought resistant. Other occupations in this sector are concerned with the development and supply of genome editing systems. These are used for the genome editing practices. Furthermore, occupations in upstream supporting sectors belong to the making sector as well. Any occupation working with technologies that help developing genome editing systems or genome editing crops thus fall in this category too.
Applying sector	This sector consists of farmers and agricultural labourers concerned with the process of planting, managing (fertilizing and irrigating f.e.) and harvesting the genome edited crops.
Complementary sectors	These sectors consist of occupations that facilitate or inhibit the implementation of genome editing technologies. This, for example, includes university teachers or transporters of the crops.
Quaternary sectors	These are sectors that are producing discretionary goods. They will be affected by spill over effects from other sectors. Genome editing will affect the disposable income in the previous three sectors, which will be spent on goods in the quaternary sectors.

[1] The terms used slightly differ from those used by Vermeulen et al. (2018) in their framework. They refer to 'types of occupations', instead of 'impact on occupations'. Furthermore, they refer to 'existing occupations', which cover both substituted as well as remaining occupations, 'exploiting & transforming occupations', and 'emerging occupations.' The terms are altered to capture the meaning of the concepts more clearly.

This task-based framework helps to provide a comprehensive overview of the jobs that are affected by new technological developments, how they are affected, and in which sector these jobs are situated. I will use this framework to study the expected impact of genome editing on labour.

Complementary to the framework of Vermeulen et al. (2018) I will also investigate which type of country these jobs are likely to be situated in: developed or developing countries. According to literature (Cirera & Sabetti, 2019; Vivarelli, 2014), the labour implications vary depending on the level of development of a country, so this should be accounted for.

I will not investigate the category of remaining occupations, which is one of the possible job impacts proposed by Vermeulen et al. (2018). I concluded that more meaningful insights will be reaped by only focusing on jobs of which genome editing technologies will impact the range of tasks. If the job stays the same in terms of tasks performed the only meaningful finding would be to analyse the extent to which the demand for these workers increases. However, because the technology is in an early stage of development, there is no data available regarding the extent to which jobs are affected. Therefore, I only focus on which jobs are affected in terms of tasks. Furthermore, the labour implications for the quaternary sector will be outside the scope of this thesis too. The indirect effects on disposable income in the making, applying, and complementary sectors will be too difficult to measure. Again, genome editing technologies are in a very early phase of development. Many labour implications are therefore yet to happen. Hence it is impossible to make meaningful estimations concerning disposable income.
I will thus analyse how tasks will be impacted by genome editing and how this will affect jobs: if will they be substituted, transformed, or newly created. These occupations will be categorized according to the sectors they belong to and the type of country they are expected to be in. By also investigating if the affected job is likely to be situated in a developed or developing country, and because I do not account for remaining jobs and the quaternary sector, the framework of Vermeulen et al. (2018) is transformed. The transformed framework can be found in Table 3.

Table 3: The transformed framework of Vermeulen et al. (2018) that is used to study the labour implications of genome editing.

	Making sector			**Applying sector**			**Complementary sector**		
	Job description	Tasks	Developed/ Developing country	Job description	Tasks	Developed/ Developing country	Job description	Tasks	Developed/ Developing country
New jobs									
Transformed jobs									
Substituted jobs									

3. Methodology

We know that labour implications of other technologies, such as automation and digitalization, have received substantial academic interest over the past years (Acemoglu & Restrepo, 2018; Dachs, 2018; Ernst et al., 2019; Korinek & Stiglitz, 2017; Vermeulen et al., 2018). There are several indications that genome editing is likely to have effects on jobs too. This thesis aims to identify how crop genome editing will affect employment and in which sectors and countries jobs will be situated, based on the technology's effect on tasks.

To achieve the aim of this thesis, a qualitative research design is appropriated. Research investigating labour implications of other technologies such as automation and digitalization did this ex-post by using data available in existing labour databases (Artuc et al., 2019; Autor, 2015; Carbonero et al., 2018). However, genome editing is at an early stage of development and thus, the data is unavailable.

The studies' exploratory aim is best achieved by a qualitative research design as this is suitable for gaining an understanding of an unstudied field (Bryman, 2016). However, due to the absence of empirical data and no mention of the effect on jobs of genome editing in current research, the labour implications of genome editing are considered an unstudied field that is yet to be explored (Stewart et al., 2008).

To identify the expected labour implications of genome editing, I adopted expert interviews as a qualitative research method. The experts are at the frontier of crop genome editing and familiar with the current research and recent developments of this technology. Therefore, qualitative research enables one to acquire a deeper insight into these experts' perspectives by identifying what he or she deems important (Bryman, 2016; Hammarberg et al., 2016; Stewart et al., 2008). Furthermore, because the experts have specific knowledge of the topic of this thesis, it was expected that through conducting qualitative research, it is possible to identify what the essential labour implications of genome editing are (Littig & Pöchhacker, 2014).

3.1 Data collection

3.1.1 Interviewee selection

For the data collection, two sampling methods were used. First, expert sampling is adopted as a form of purposive sampling. This sampling strategy is commonly used when participants are needed who have specific knowledge of the topic at hand (Etikan, 2016). After that, snowball sampling was used.

The participants were selected by applying predefined criteria to increase the study's reliability (Bryman, 2016). Two types of experts were chosen. First, scientists in the field of crop genome editing, hereafter referred to as 'genome editing experts', were asked to participate. These scientists have knowledge about the state-of-the-art research of the technological developments and how these are expected to affect jobs. This is crucial information for understanding labour implications is exclusively possessed by genome editing scientists. Second, experts in the field of labour implications of agricultural technological innovations, hereafter referred to as 'labour experts', were asked to participate. These labour experts have in-depth knowledge about how technological innovations affect jobs in the agricultural and complementary sectors. Therefore, they have provided insights into how genome editing could affect employment, given the development of other agricultural technologies. Therefore, they were asked to provide insights on how genome editing would behave in terms of labour effects, given the paths of other agricultural technologies.

Research shows that labour implications vary between developed and developing countries. Therefore, I asked experts that are affiliated with organizations from both types of countries. To identify if the expert's organization is situated in a developed or a developing country, the country classification list of the United Nations (2020) was used, which can be found in Appendix A. This list assesses the level of economic development of a country and distinguished between developed and developing economies (United Nations, 2020).

To select both genome editing experts and labour experts, I sought out scientists who wrote the most-cited articles in crop genome editing and the field of labour implications of agricultural technological innovations. Sampling the most-cited experts is suitable for identifying scientists with the greatest expertise in the field because citations represent an article's scientific impact within its field. Furthermore, citations indicate recognition by peer scientists in the same field and, therefore, by proxy, of expertise (Aksnes et al., 2019). To identify those most-cited articles, and thus the authors in the two fields of expertise, I searched the Web of Science Database. The keywords that were applied in the search can be found in tables 4 and 5. Concretely, the keywords were chosen iteratively by adding keywords identified in papers found in previous searches and deemed helpful in the final search.

A specific period was chosen for the search on crop genome editing articles. The time frame was set to 2012-2021, driven by the fact that in 2012 CRISPR/Cas was invented. This invention was an enormous breakthrough that significantly shaped future research on the possibilities of genome editing (COGEM, 2019; Ricroch, 2019). Therefore, it was assumed that articles published before 2012 could not provide well enough insights into the modern applications of genome editing technologies, which was necessary to investigate the labour implications.

Table 4:Search query for genome editing technologies used in crops.

Genome editing in crops
TOPIC: (gen* edit* OR gen* engine* OR crispr* OR talen*) *AND* **TOPIC:** (crop* OR plant*) *AND* ***YEAR**:* (2012-2021)

Table 5: Search query for labour effects of technologies in the agricultural sector.

Labour effects of technologies in the agricultural sector
TOPIC: (robot* OR digit* OR automat* OR technolo* OR mechan*) *AND* **TOPIC:** (agri*) *AND* **TOPIC:** (labor* OR labour* OR employm* OR occupat* OR job*) *NOT* **TOPIC:** (laborat or*).

In total, the search on genome editing articles resulted in 16.559 articles, of which 3.209 were review papers. The search on articles covering labour effects of technologies in the agricultural sector resulted in 4.171 articles, of which 339 were review articles. For this research, review articles were more valuable than general articles, as it was assumed that review papers provide a broader understanding of how genome editing technologies are used in crops or how technologies generally affect labour in the agricultural sector. This broader perspective was considered extra valuable because it was thought that general labour implications could be derived easier from broader insights than from specific cases often described in general articles. In some cases, the article that resulted from the search query did not fit the aim of this thesis. These were articles that were not focused on the use of genome editing in crops, or articles that did not explain the labour effect of a technology in the agricultural sector. These articles were removed.

For the search on genome editing in crops, the authors of the 1% most-cited articles were identified as potential interviewees. The highest cited 10% of authors were selected for articles on labour effects of technologies in the agricultural sector. Both are standard thresholds to identify the articles with the highest impact within a specific research field (Waltman & Schreiber, 2013). A different threshold was chosen for both search queries to reach a more balanced sample of experts, as the number of search results differed per field of expertise. Since experts from developing countries were less cited than those from developed countries, the search resulted in significantly more experts from developed countries. Therefore, after identifying the authors of the most-cited 1% and 10% of the articles on crops genome editing and labour effect of technology in the agricultural field, respectively, the search continued exclusively for authors from developing countries until respectively 2% and 20% of the most-cited papers were screened. These percentages are commonly used thresholds as well (Waltman & Schreiber, 2013).

Regarding the specific selection of potential interviewees, authors of review articles were asked to participate first. Hence, first, the 1% most-cited authors of review papers on crop genome editing were contacted, and 10% most-cited authors of review papers on labour effects of technology in the agricultural sector. However, the response rate was not high enough to acquire a meaningful sample. Therefore, the authors of regular papers were asked too. Furthermore, only the first authors of the most cited articles were asked to participate in the study since it was assumed that generally, the first author is most familiar with the research. Also, one author per article leads to a more diverse spectrum of perspectives, assumingly resulting in more interesting findings.

This sampling strategy led me to reach out to 37 genome editing experts who wrote a review paper and an additional 72 genome editing experts who wrote a regular paper. Eight authors of review papers and ten authors of regular papers were eager to participate. 34 Labour experts that wrote a review article on the labour effect of technological innovation were reached out to. Additionally, 30 authors of regular papers were reached out to as well. Only two authors of a review paper and two authors of regular papers wanted to participate

The second sampling strategy that was used was snowball sampling. The participating authors were asked if they knew other scientists that might know about this topic. Snowball sampling was used because the response rate of the most-cited experts in both fields was low. By using

snowballing, the experts could identify other scientists that they considered suitable for giving interesting results. This resulted in ten genome editing experts asked to participate, of whom seven were willing to cooperate. Additionally, eight other labour experts were asked, and six wanted to participate. The snowball sampling was done simultaneously with the expert sampling. At some point, I stopped asking more experts identified by expert sampling because the desired number of participants, which was 30, was reached.
Besides the two sampling methods used, one interviewee from Utrecht University was asked to participate because it was known that he is an expert in genome editing who paid attention to labour implications as well.

The two sampling methods and the one extra interviewee asked resulted in a sample of 33 participants, of which 24 were genome editing experts and nine labour experts. In total, six interviewees were from developing countries, of whom one was a labour expert. Because of the large sample, the reliability of the results is increased. The chance that data outliers will significantly affect the results is minimalized (Bryman, 2016). An overview of all participating interviewees can be found in Table 6.

3.1.2 Interviews

Semi-structured qualitative interviews were chosen as the data collection method. Interviews intend to gain insights into individuals' views about specific matters (Gill et al., 2008) – the jobs that are affected by genome editing in this case. Semi-structured interviews are deemed a fitting data collection technique because they offer the researcher guidance in the form of predetermined topics, while still allowing for flexibility during the interview (Bryman, 2016). Therefore, a list of predetermined questions was asked to all interviewees in the form of an interview guide, which can be found in Appendix B. These questions were formulated to investigate those aspects required to successfully answer the research question (Bryman, 2016). To do so, they were based on the framework developed by Vermeulen et al. (2018) that was used to study the labour implications of genome editing. Concretely, this means that I asked how they expect jobs to be affected based on the effect genome editing has on tasks, in which sector they expected this to happen, and if this effect is foreseen to happen in developed or developing countries.

Table 6: Overview of the interviews ranked based on interview date.[2]

Interview #	Name of interviewee	Type of expert	Country of the affiliated institution	Developed/ Developing	Duration of the interview
1		Genome editing	The Netherlands	Developed	53 minutes
2	Dr. Xingliang Ma	Genome editing	Canada	Developed	63 minutes
3		Genome editing	The United Kingdom	Developed	52 minutes
4		Genome editing	The United Kingdom	Developed	52 minutes
5		Genome editing	The Philippines	Developing	58 minutes
6		Genome editing	The United States	Developed	71 minutes
7		Genome editing	The United Kingdom	Developed	65 minutes
8		Genome editing	The United States	Developed	56 minutes
9		Genome editing	The United States	Developed	58 minutes
10		Labour	The United States	Developed	31 minutes
11		Genome editing	The United Kingdom	Developed	34 minutes
12		Genome editing	Bangladesh	Developing	56 minutes
13		Genome editing	The United States	Developed	55 minutes
14		Labour	The United States	Developed	56 minutes
15		Genome editing	The United States	Developed	43 minutes
16		Genome editing	China	Developing	55 minutes
17		Labour	Canada	Developed	45 minutes
18		Genome editing	China	Developing	30 minutes
19		Genome editing	The Netherlands	Developed	45 minutes
20		Genome editing	Australia	Developed	57 minutes
21		Labour	The Philippines	Developing	54 minutes
22		Genome editing	The Philippines	Developing	52 minutes
23		Labour	Canada	Developed	47 minutes
24		Labour	The Netherlands	Developed	45 minutes
25	Dr. Stan Oome	Genome editing	The Netherlands	Developed	42 minutes
26		Genome editing	The United States	Developed	55 minutes
27		Labour	The United States	Developed	51 minutes
28		Genome editing	The Netherlands	Developed	81 minutes
29		Genome editing	Belgium	Developed	42 minutes
30		Genome editing	The Netherlands	Developed	30 minutes
31		Labour	The Netherlands	Developed	44 minutes
32		Genome editing	The Netherlands	Developed	42 minutes
33		Labour	The Netherlands	Developed	59 minutes

[2] The information received by the participants is handled with care and ethical responsibility. The interviewees were asked for their consent at the beginning of the interview and were anonymized to ensure confidentiality. Only if the interviewee asked not to be anonymized I included their names.

3.2 Data analysis

After the interviews were transcribed, the data was coded. Coding was performed in Microsoft Excel. Coding refers to "the operations by which data are broken down, conceptualized and put back together in new ways" (Flick, 2018, p.455). The interviewees' statements were coded in an iterative yet structured manner to ensure the reliability of the coding process. Furthermore, an open coding approach was adopted, as the focus lies on breaking down and categorizing the large batch of data available (Bryman, 2016). In detail, the data analysis was carried out as described in the following.

The coding process was structured according to the framework developed by Vermeulen et al. (2018) to study the labour implications of genome editing. First, pieces of raw data, meaning sections of the transcribed interviews, were categorized according to whether this section concerned a new, transformed, or substituted job and in which sector this job was situated: making, applying, or complementary. This resulted in an overview of all raw data sections being categorized along the framework of Vermeulen et al. (2018) (see Appendix C). Subsequently, per interviewee, the pieces of raw data were analysed and coded to retrieve the job name, the tasks that are new or substituted, and in which type of country they described the job to be situated in. The final coding framework emerged and can be found in Appendix D.

The coding was done iteratively. Throughout this coding process, next to the affected jobs, the interviewees also foresee certain factors that are conditional for the labour implications of genome editing. These conditional factors, discussed further in the result section, are the regulations, public perception, and the prevailing agricultural system. Hence, a new coding category was created including each conditional factor, and raw data were coded and analysed according to each of these factors.

4. Results

This section provides the insights derived from the 33 semi-structured interviews with experts. I found that the expected labour implications of genome editing are very diverse. Experts foresee many different jobs to be affected. In general, it is expected that genome editing will lead to jobs being created, transformed, and substituted. In the making sector, jobs are expected to emerge and transform. In the applying and complementary sectors there are jobs expected to emerge, transform, and become obsolete. The sample of interviewees consists of both genome editing experts and labour experts, which contributes to the diversity of the results. While both expert types mention most findings, some are mentioned predominantly by either genome editing or labour experts. Therefore, it proved very useful to ask these two types of experts, as otherwise, specific implications would not have been addressed. The number of interviewees per expert type that mentions how jobs to be impacted per sector can be found in the overview provided in Figure 2.

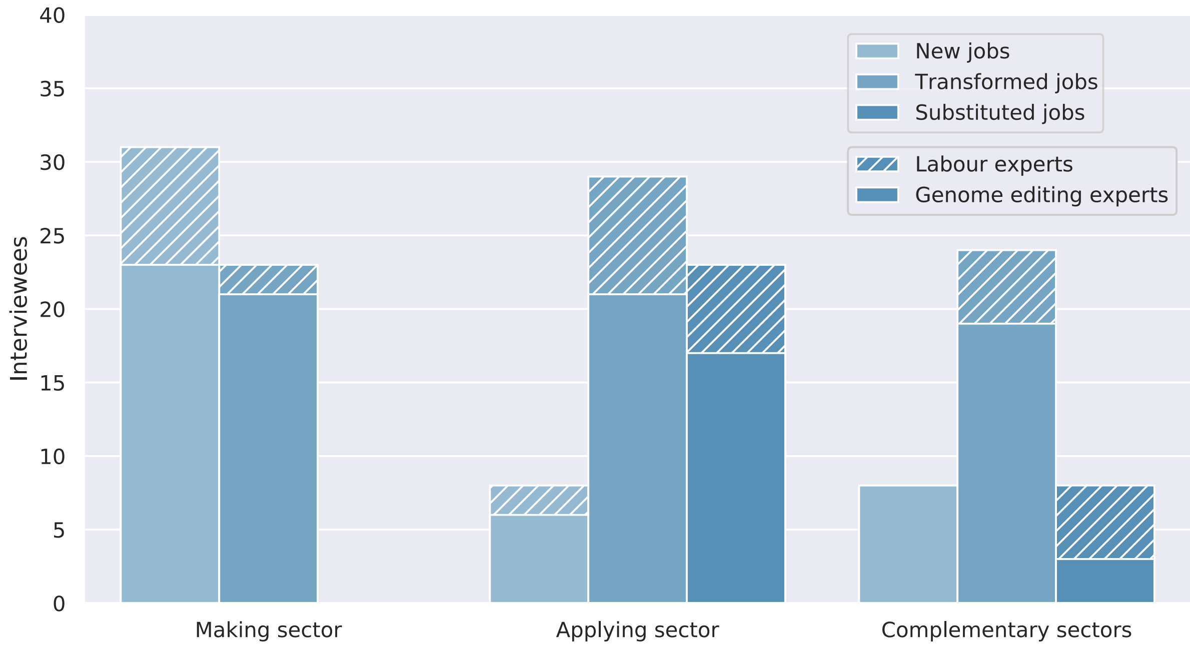

Figure 2: Overview of how the different expert types expect the jobs in the three sectors to be impacted.

The interviewees say that all the findings are dependent on certain developments. These serve as conditional factors that shape the subsequent labour implications of crop genome editing in each sector. Therefore, I will first discuss these conditional factors mentioned by the experts. Thereafter, the effect that genome editing will have on jobs is discussed according to the three sectors of the framework of Vermeulen et al. (2018).

4.1 Conditional factors

The experts identify numerous ways of how they expect jobs to be impacted across sectors. However, they emphasize that these labour implications of crop genome editing are conditional upon several contextual factors. This means that the eventual impact on an occupation depends on the status of the conditional factors. The experts mention three conditional factors that determine which and how jobs will eventually be impacted.

First, experts mention that regulation has a strong influence on the labour implications of crop genome editing. This is mentioned by 21 of the 33 interviewees (Interviewee 1, 3, 4, 5, 6, 7, 8, 11, 16, 18, 21, 22, 24, 25, 26, 27, 28, 29, 30, 32, 33), both genome editing and labour experts. They argue that the labour implications will be different depending on if the regulations are strict or lenient. Interviewee 28 (genome editing expert) explains the relationship between labour implications and regulation as follows: "This totally depends on, I think, how future legislation looks like, so what kind of procedures you need to go through to get it to the market". However, this is uncertain because many countries are still exploring which regulatory pathway to choose. The United States, for example, adopted a lenient regulatory approach. Contrastingly, the European Union decided to regulate genome editing as strictly as genetically modified organisms (GMOs), which are the precedent of genome edited crops. Because of regulatory blockades, it is costly to get these GMOs to the market. Therefore, it is only developed by a few large agricultural companies and applied to a few crops (Ricroch & Hénard-Damave, 2016). The European Union is, however, prompting a discussion to renew the regulatory approach towards genome editing.

The experts foresee that it is unlikely that genome editing will be developed and used substantially in crops if the technology is strictly regulated. This would mean that genome editing will have fewer labour effects across the three sectors. Contrarily, if genome editing were regulated more leniently, the experts foresee that it will be developed and applied to various crops. This means that it will impact jobs in more ways than when strict regulations are adopted. "What makes a major difference is if some of the products would be regulated as non-GM. I think that would have a lot more influence because then a lot more products would be developed by gene editing" (Interviewee 22, genome editing expert).

Because of the broader range of opportunities in countries where genome editing is regulated less strictly, the experts foresee jobs to move to countries that adopt more lenient regulations. "It is the case that companies move out of Europe. (…) If they cannot do it here, they will invest in doing it where they can" (Interviewee 11, genome editing expert). Interviewee 25 (genome editing expert) highlights this as well when talking about jobs in the applying sector: "if we produce twice the number of potatoes in China because they were allowed to alter genes, then we go there".

The same is true for public acceptance, which is the second conditional factor mentioned by the interviewees. One-third of the expert mentioned this (Interviewee 1, 2, 4, 5, 10, 24, 25, 27, 28, 30, 33), both genome editing and labour experts. They mentioned that the labour implications would be different if public acceptance towards crop genome editing is broad compared to low public acceptance. According to the interviewees, crop genome editing will be more widely developed and used if public acceptance increases. Broader public acceptance will thus lead to more labour implications. Interviewee 27 (labour expert) explains this conditional relationship as follows: "It depends on whether the market will exist for those products. And the market will exist only if the public views the technology as something good for the environment, for the health, or public health".

The third conditional factor mentioned by the experts is the agricultural system that genome editing will be used for. This factor was mentioned by sixteen of the interviewees (Interviewee 1, 4, 5, 7, 9, 10, 12, 13, 14, 16, 17, 23, 24, 28, 31, 33). Relatively more labour experts brought this forward than genome editing experts. An agricultural system is a system that produces crops existing of interrelated actors such as farmers, agricultural policymakers, processors, and supermarkets. Those actors share social, political, and economic components, which determine how they interact with each other (Drinkwater et al., 2016). The agricultural system determines the actors that will develop the technology, the purposes it will serve, and what crops will be produced utilizing genome editing.

The interviewees identified two types of systems, which I will refer to as the 'neoliberal agricultural system' and the 'inclusive agricultural system'. The labour implications are depending on which system will prevail, as "that's going to have implications for who wins and who loses, and what kinds of labour conditions then roll out as a result." (Interviewee 23, labour expert).

The interviewees say that the neoliberal agricultural system will be dominated by large agricultural multinationals. Because of patents that these large companies will appropriate, and the large costs associated with bringing genome edited crops to the market, the development of the technology only lies in the hands of a few companies. "This genetic engineering is patented by a small number of companies. They are dominating the market" (Interviewee 9, genome editing expert). Therefore, they are expected to focus on a small number of 'big money' crops that can be industrially produced. This results in fewer labour implications in the making sector and less diverse labour implications in general compared to the inclusive agricultural system that will be discussed later.

Furthermore, the experts foresee that this system is characterized by fewer people working in the agricultural field. They expect a mechanized way of agriculture to be adopted, leading to less labour needed in this sector. Interviewee 23 (labour expert) expects that this neoliberal system is "going to promote and encourage precision agricultural systems that will likely rely far less on agricultural skilled labour and more so on technologies". Experts also expect that smallholder farmers will become primarily dependent on the large multinational's developed seeds. At some point, the small holder farmer will collapse, and industrial agriculture will take over the small-scale way of farming. "They provide genetically modified seeds at a relatively low price to the small farmer. They are growing fast, and they produce really good quality crops, so they are satisfied. And then what? The seed producing companies increases the price" (Interviewee 9, genome editing expert). The same expert explains later that this will result that "in the long term, the small farmers' business will go down".

The second system the interviewees identify is the inclusive agricultural system. This system is characterized by more players developing the technology. More biotech companies can enter the market, hence increasing inclusivity. According to the interviewees, this largely depends on how stringently genome editing is regulated and thus how expensive it is to bring new crops to the market. If genome editing is regulated less stringently, then "it could also be affordable (…) for smaller breeding companies to breed varieties and bring it to the market" (Interviewee 1, genome editing expert). They are expected to focus on other crops and traits than the 'big money' ones that large multinationals focus on. Because more players will develop a greater diversity of crops and traits, the labour implications are expected to be more diverse than in the neoliberal agricultural system.

"I hope that with CRISPR, you are able work in niche plants, not only wheat, maize, soybean, but you can also start working with a lot of niche crops. And you can work on niche traits that have diversified applications that people have a more positive association to" (Interviewee 4, genome editing expert).

The interviewees expect that these crops and traits are not only developed for industrial farming purposes but also for smallholder farmers and other types of farming such as biological farming and regenerative farming. This contributes to the inclusivity of this system. For example, interviewee 2 (genome editing expert) explains that it could be that a crop that is important for a local community "could not draw enough attention previously, as the profits might be low (…) but with gene editing, we have the potential to improve it". Because more types of farming can thrive because of genome editing in this inclusive agricultural system, the labour implications are more diverse than the neoliberal agricultural system.

The following section will discuss the labour implications of crop genome editing in the making, applying, and complementary sectors. How these labour implications unfold is thus conditional upon the regulations, public acceptance, and agricultural system prevails. For example, if genome editing should lead to new jobs being created at small breeding companies, then those jobs will only be created if regulations do not ban genome editing. In a similar vein, jobs concerned with spraying pesticides are expected to be substituted if genome edited crops are developed that are resistant to certain pests, as I will discuss in the section on the applying sector. However, this is unlikely to happen if the neoliberal agricultural system prevails. Companies such as Syngenta and Corteva are selling agrochemicals and are also expected to develop the genome editing technologies in this neoliberal system. It is assumed that they will focus on different traits than making crops resistant to pests. "Are sales going to be tied together? (…) some large companies have interests in the use of chemicals in agriculture and produce seeds as well. (…) which choices are they going to make?" (Interviewee 31, labour expert).

4.2 Making sectors

Jobs in this sector focus on developing genome editing technologies and developing new crops using these technologies. Workers in upstream sectors, who are supporting the development of genome editing technologies and their use, are also accounted for in the making sector.

The main finding for the making sector is that experts predominantly foresee new types of jobs to be created, some jobs to be transformed, and expect no jobs to be substituted. 32 Out of 33 interviewees expect new jobs to be created in the making sector. They foresee more newly created occupations to emerge in the making sector than in the applying and complementary sectors. Five new types of jobs are expected to emerge. These are created because new tasks emerge due to the introduction of crop genome editing that do not easily fit within existing jobs.

First, the experts mentioned the bioinformatician to emerge due to the task of discovering the genetic functions of a crop. Second, the genome sequencer is a new job. This person's task is mapping the genetic sequence of a crop. Third, scientists with the task of developing genome editing technologies emerge. Last, the genome editor who modifies a crop's genome is a new job that is expected to be created.

In addition to new jobs, the experts foresee three types of jobs to transform. These jobs transform because of the emergence of new tasks that complement the use of genome editing technologies and because other tasks are substituted by genome editing. 23 out of 33 experts expect transformations of jobs due to genome editing in the making sector.

First, the breeder's job is expected to transform. The experts foresee that the breeder's job changes by adopting a new task: modifying a crop's genome. Another task of the breeder is expected to be substituted by genome editing: crossing and backcrossing crops to get the desired crop variation. Second, the experts foresee that the job of scientists performing fundamental research transforms. Their tasks change because they adopt a new technology as a research tool that they use to investigate different crop species. Last, the job of the marketeer of genome edited crops is expected to transform. His or her new task will be to develop a consumer-oriented marketing strategy, instead of a marketing strategy associated with industrial agriculture.

All new tasks that emerge require a high level of technical expertise or communication skills and can therefore be characterized as abstract tasks. As literature has shown, technological innovation generally leads to an increased demand for such tasks. The task that is substituted is routine based. This is also in line with research, which emphasizes that routine-based tasks are prone to become substituted by the technology (Autor, 2015; Goos & Manning, 2007).

According to the interviewees, jobs that emerge and transform in the making sector are situated in both developed and developing countries. Because of the low costs of developing the technology and the relative ease of using it, the experts expect this to happen in both types of countries. This contrasts with earlier research, which suggests that developing countries are more likely to import technological innovation because of a less developed making sector (Vivarelli, 2014). This would mean that it is less likely that new jobs are created and transformed in developing countries.

Genome editing experts have predominantly mentioned most jobs that emerge or transform in the making sector, as opposed to labour experts. The reason for this might be that the genome editing experts are working within the making sector and thus have a clearer view of the developments within that sector and how this affects jobs.

4.2.1 New jobs

Most new occupations mentioned by the interviewees are expected to emerge in the making sector. They mentioned four types of occupations. These are the following four jobs: bioinformaticians in the private sector and research institutes, scientists developing new genome editing systems in research institutes, lab workers in the private sector who map the genome sequence of crops, and genome editors working in the private sector or research institutes.

The first type of occupation that is newly created is the bioinformatician. He or she will focus on linking genetic functions to the DNA sequence of the crop. 32 Out of 33 experts mentioned this.

The main task which is fulfilled by these bioinformaticians is to link genes to their genetic function. This is done by analysing genetic data derived from the genome sequence of a crop, which can be retrieved from genetic sequencing technologies. Genome editing is used "as a gene discovery tool. To say: this is an important gene" (Interviewee 3, genome editing expert). Because of the enormous number of genes and their combinations that can lead to different functions within the crop, this data is screened by information technologies and algorithms to derive the genetic variance with the characteristic that is aimed for. This job is for people that are acquainted with both molecular biology as well as information technologies. "You can't do genomics if you don't do bioinformatics (…) You must interpret the data. And you need tools to do that. And those tools define the targets you are going to edit." (Interviewee 5, genome editing expert). Interviewee 29 (genome editing expert) explains this process as follows:

> "You can only do genome editing if you have knowledge about the genes and genomes. That is based on knowing: gen X is related to that, and if I do this in that gen, that will happen. And to make genome editing more efficient at a larger scale, people will use data mining and sequencing databases to retrieve genetic knowledge. (…) These people are bioinformaticians, people with knowledge about biology and informatics. They are not in the laboratory, but behind a computer to interpret the data"

The task of linking genes to their genetic function requires a high level of technical expertise in both molecular biology and bioinformatics and can therefore be described as an abstract, non-routine task.

The interviewees foresee that these people will work for breeding companies, biotechnology start-ups, and spin-offs from research institutes. They are expected to arise primarily in developed countries at first. That is because more genetic data is available of crops cultivated in developed countries, such as wheat and corn. "Research is centred on big money crops, that grow mostly in developed countries (Interviewee 7, genome editing expert). In developing countries, the bioinformaticians have little genetic information to work with yet. However, the expert view is that bioinformaticians will emerge in developing countries too once the genetic sequence of more crop species has been mapped. The technology itself is cheap and relatively simple to adopt for analysing purposes. Interviewee 2 says that "for developing countries, gene editing is indeed an opportunity to catch up (…) it is much easier to use in any plant research lab". Experts thus expect that this development phase might just as well occur in developing countries when the needed information is present. This contrasts with VIvarelli (2014), who argues that technology development occurs in developed countries and is subsequently transferred to developing ones. Interviewee 7 (genome editing expert) explains it as follows:

> "I know about initiatives in developing countries that have used genome editing quite successfully to tackle crop health issues. They all have been supported by I think, national or international funds. But in the future, I don't see why this could not (…) promote the generation of a spin off. I don't think it will be limited to developed countries".

The second type of job that is expected to be newly created concerns genetic engineering scientists who improve the process of genome editing itself. Ten genome editing experts mentioned this and none of the agricultural labour experts (Interviewee 1, 2, 4, 6, 7, 16, 18, 20, 28, 30). The tasks of these scientists are centred on improving these systems by making them more precise and efficient. The interviewees indicated that genome editing systems are continuously evolving. "Since the end of last century, there has been research groups emerging designated for developing more efficient gene editing tools. Like ZFNs, TALENs, CRISPR-Cas9, CRISPR-Cpf1 etc.". (Interviewee 2). These tasks require technical knowledge about genetic engineering and well-developed research skills. They can thus be described as abstract, non-routine tasks. For example, interviewee 20 (genome editing expert) says that: "This type of job is not an ordinary job. It is really highly skilled research". An example of how these scientists develop an improved genome editing system is given by interviewee 20 (genome editing expert).

"Some people engineer the Cas-line, the enzyme. To make them more specific or more efficient. For example, the traditional Cas-line is sequence dependent, meaning they can only go to certain genome position to do this editing. So, some people are making this Cas-line more flexible so they can go to anywhere you want to do the job.

The scientists improving the genome editing systems are expected to be working in research institutes in developed as well as developing countries. Interviewee 6 (genome editing expert) gives an example about genome editing systems being developed in China, a developing country (United Nations, 2020).

"A lot of scientific publications in my field come directly from China. Earlier it was a Chinese name in an American lab, but now they come from Chinese labs. So, in the last years it is not only production that come from developing countries such as China, but also technology development".

Therefore, it can be concluded that in the phase of developing the technology itself, jobs are emerging in developed and developing countries. However, here too, my findings differ from the notion that it is unlikely that technological innovation is developed in developing countries.

A third occupation that is newly emerging is the lab worker who maps the genome sequence of crops. Six interviewees have said this, who all are genome editing experts (Interviewee 1, 16, 25, 26, 28, 32). In the last years, enormous developments have been made in so-called Next Generation Sequencing Technologies, which are technologies developed to map the entire genomic sequence of an organism. These are upstream technologies that facilitate the development and use of genome editing. The sequencing is done in Next Generation Sequencing machines that map an organism's genetic sequence at an unprecedented rate and inexpensively compared to previous sequencing technologies (Nguyen et al., 2019). The experts say that the tasks of these lab workers concern running these machines by inserting the DNA sample and retrieving the genomic sequence from it. However, the interviewees did not further elaborate on the tasks. Therefore, I investigated literature on the steps of the sequencing process that the lab workers need to undertake. Literature shows that these lab workers are involved in library preparation, which is getting the DNA sample ready to be sequenced. In addition, they perform data analysis, which concerns validating the useability of the data and mapping the genes to a specific location in the genome (Gogol-Döring & Chen, 2012; Van Dijk et al., 2014). Because of the technical knowledge and expertise in molecular biology and informatics that is required, they can be categorized as abstract tasks.

The sequencing of the genetic material of a crop happens in specialized sequencing companies both in developed and developing countries. “These are generally large companies, such as Novogene, which is located in China and Europe as well” (interviewee 25, genome editing expert). Interviewee 12 (genome editing expert) explains how this works in practice: “We now send the materials to the sequencing company in China or other countries, and we are getting within two weeks the sequenced result”. Because the technology evolves so rapidly, a new machine is brought to the market every few years, which can map a genetic sequence more efficient than its predecessors. The sequencing companies have many Next Generation Sequencing machines working at almost an industrial scale, which decreases the costs of the process. Therefore, companies and universities outsource the sequencing activities to these companies. Interviewee 25 (genome editing expert) illustrates how this works:

> “The problem when you want to buy these sequencing machines is that you have a lifecycle of about four years. Every one or two years a new machine enters the market that can handle double the amount of data for the same price. (…) That is exactly the reason why also many universities outsource this now”.

The last type of job that the experts foresee is the job of the genome editing itself. This was mentioned by only a handful of interviewees (Interviewees 7, 11, 12, 20, 22, 28) who were all genome editing experts. These genome editors will be concerned with the tasks of transforming the genomic sequence and test whether the desired traits have been introduced correctly. This step requires technical molecular biotechnology knowledge and is thus an abstract, non-routinized task. There are different transformation steps and different ways of introducing the desired trait in the crop’s cell per crop variety. The reason why only a few interviewees mention this to be a newly created job is that most experts expect that the breeder will adopt these tasks. This transforms the job of the breeder, which I will elaborate on in the next section.

The experts expect these genome editors to work for specialized private companies on a commission basis. They will retrieve samples from breeding organizations and perform the modifications: “We can ask a company and send them the seed: ‘please do the editing for us’ (Interviewee 12, genome editing expert). They expected these companies to be situated in developing countries, because of the low wages. Interviewee 20 (genome editing expert) mentions China, a developing country, as an example: “They are more cost-effective labour-wise”.

4.2.2 Transformed occupations

In addition to the new jobs, the interviewees also expect that genome editing will transform jobs that already exist within the making sector. They identified three job types that they expect to transform: plant breeders in the private sector, scientists doing fundamental research, and marketeers of genome edited crops.

First, half of the interviewees foresee that the job of the plant breeder will be transformed (Interviewee 1, 2, 3, 5, 6, 7, 8, 14, 18, 20, 22, 25, 26, 28, 29, 32). The transformation of breeder’s job occurs because certain tasks of the breeder will be substituted by other tasks. The experts foresee that a new task for the breeder will be to modify a crop's genome. In the section on new jobs in the making sector, I discussed that some experts foresee that this task will lead to a new job emerging. However, most experts believe that since the application of genome editing technologies is straightforward, it is likely that the breeder will adopt this task. As Interviewee 2 (genome editing expert) says: “I do not see the difficulty of converting into gene editing”. The experts think it is likely that the same people can be trained to use genome editing technologies: “I think crop breeding has evolved a long way already: a lot of readers familiar with molecular biology tools for marker assisted selection and so on. So, I don’t think be too much of a leap to start using gene editing” (Interviewee 3). Modifying a crop’s genome requires technical expertise in molecular biology and is an abstract task that is hard to routinize.

The task of modifying the genome of a crop will substitute the tasks of crossing and backcrossing crops to get the end-product with the desired result. “Traditional breeding is that the breeder goes to the field, find parents who they will be crossing, and then go to the progeny, looking for the variation” (Interviewee 20, genome editing expert). This, however, is a randomized process that causes a lot of unwanted mutations. So, to get the desired mutation in a crop, without the unwanted ones, the breeder must perform backcrossing.

> “There are like, I don’t know how many of thousands of mutations in your plant, so what they have to do afterwards is to backcross them with the ‘normal plant’ so to say, to keep the mutation that you wanted and get rid of all the others. These are extremely extensive, labour-intensive steps that take a lot of time and a lot of hands-on and a lot of years and money” (Interviewee 1).

With genome editing, the task of crossing and backcrossing is not necessary anymore because genome editing enables a “breeding by design approach” (Interviewee 6, genome editing expert). These tasks that are substituted are routine tasks. “You need to work through thousands of plants, look for mutations, and to perform DNA analysis. Because of genome editing, this routine work is not necessary anymore” (Interviewee 32, genome editing expert).

The experts mentioned that the transformed breeder is situated predominantly in developed countries, as the breeding sector is strong. However, also in developing countries, it is expected that breeders will adopt the technology and shift from conventional to genome editing oriented breeding. Interviewee 16 (genome editing expert) mentions that it does not matter if a country is developed or not: “If you have a large field and some basic knowledge about the crops’ biology, you could change the crops’ genes by genome editing”.

A second type of job that the experts foresee transforming is the scientist employed at universities or other research institutes doing fundamental research in plant science. This was mentioned by twelve genome editing experts, while no labour expert indicated this (Interviewee 1, 4, 6, 8, 12, 15, 16, 19, 20, 26, 28, 30). One of the bottlenecks of using genome editing technologies in many crop species is that little is known about the molecular systems of many species. Fundamental research on plants has been going on for many years and genome editing is “a very useful tool or technology to accelerate basic research in plant science” (Interviewee 26). An emerging task that transforms the job of the plant researcher is to investigate new crop species. Interviewee 28 (genome editing expert) explains that researchers “now have many more tools to use and can now focus on other crop species than the usual research species, because other crops are available for research now too”. These tasks require high technical expertise and therefore are performed by skilled plant researchers. Because of the technical know-how needed, this task is an abstract, non-routine task. The job of these plant researchers doing fundamental research transforms as they will use a new technology to crops they could not investigate before.

The interviewees foresee this job happening within university labs, both in developed countries and in developing countries. The funding that research receives is more important than the level of development of a country. “In China, plant research has good resources, so we could have (…) more people to do basic research. But if the government funding is not good, there are not so many jobs for basic research” (Interviewee 16, genome editing expert)

A third transformed job that the experts mentioned is the marketeer of genome edited crops. This was mentioned by one-third of the interviewees (3, 4, 5, 7, 8, 12, 13, 22, 25, 27, 30), of whom one was a labour expert. This job is transforming the job of the marketeer of GMO crops, the predecessor of genome edited crops. However, the marketeers of GMOs failed in that because they mainly focused on “traits which are associated with industrial agriculture, which has a very negative reputation” (Interviewee 4, genome editing expert). This resulted in the public acceptance of GMOs as well as genome edited crops being low. “Gene editing and GM have quite an image problem, because a few large companies ruined it” (interviewee 25, genome editing expert). Therefore, the experts foresee the marketeer's job to be transformed because if it is done in a similar way, “we get in the same loop of discussion that we have already with classic GM plants” (Interviewee 4, genome editing expert.

The job is transformed because new tasks emerge that concern convincing the public that genome edited crops are made safely and can benefit them. Interviewee 7 (genome editing expert) says that these marketeers will be “highlighting their qualities or explaining that they’re not different in terms of health concerns with the original products”. This task is more focused on consumer-oriented marketing. “Because the consumer in the end decides if a technique gets accepted” (Interviewee 4, genome editing expert). This will substitute the task of marketing them in a way that genome edited crops are associated with industrial agriculture. This job consists of tasks that require well-established communication skills and technical knowledge about how the system works and can therefore be defined as abstract tasks.

It is expected that these marketing experts will be working within organizations in the private sector, in both large multinationals and start-ups in developed countries. It is expected that the public acceptance in developed countries is lower than in developing countries. In the latter, people are convinced that genome editing can be beneficial for food security. Interviewee 12, a genome editing expert from Bangladesh, explains this as follows:

> “We need to produce enough food crops, from our limited land area, for the food security of 170 million people. So, we do not need much lobbying or marketing. If you have such a powerful technology, then the government and consumers would welcome it”.

4.3 Applying sector

The jobs in the applying sector are the occupations that perform all tasks from seeding to harvesting and the processing of the genome edited crops. In the case of genome editing, this concerns the jobs of farmers, agricultural labourers, and workers in the processing sector.

My main finding regarding the labour implications of genome editing in the applying sector is that experts mostly expect jobs to become obsolete, multiple jobs to be transformed, and some to be created. Eight interviewees expect two new types of jobs to be made: the urban farmer who will grow crops with niche traits in urban areas and the farmer that starts cultivating crops in areas where no agriculture was possible before.

Twenty-nine of the 33 interviewees mentioned jobs to transform in the applying sector. Two jobs are expected to be transformed: the farmer and the agricultural labourer. The job of the farmer can transform in multiple ways, depending on the traits that are edited. The experts identified five ways genome editing could change the job of the farmer and one way how the agricultural labourer's job is changed. First, the experts foresee farmers engaging in a more sustainable way of agriculture because crops are engineered without needing as many chemicals as before. Second, other farmers are expected to start growing herbicide-tolerant crops, which substitutes the need for weeding. Third, genome editing can stimulate industrialized precision agriculture, which transforms how the farmer manages their farm. Fourth, genome editing can alter the cultivation time and harvesting windows of crops and thereby change when the farmers should engage in certain practices of the production process. Last, farmers can start cultivating different crop species that could not thrive in the local environment before. The tasks of the farmer change depending on the crop that is cultivated. The latter is also expected to transform the job of the agricultural worker.

The interviewees expect mostly jobs to be substituted in the applying sector. Twenty-four of the 33 interviewees said this. Three jobs are expected to become obsolete, which is more than in the making and complementary sectors. Genome editing is expected to substitute the following tasks: weeding, spraying chemicals, harvesting, and field management. Therefore, the agricultural labourers that were performing these tasks are expected to become obsolete. Additionally, the processing labourer involved in selecting and separating crops is expected to become substituted. Last, the interviewees mentioned the smallholder farmer to become obsolete. However, this is not because their tasks are replaced by genome editing but because the experts foresee a neoliberal agricultural system that pushes them out of practice.

Most newly created tasks are non-routine tasks, which is in line with the type of tasks that scholars have argued to increase in demand as a result of technological innovation (Autor, 2015; Goos & Manning, 2007). I found that the tasks that become substituted due to genome editing are routinely based, but low-skilled labourers perform them. This differs from the argument brought up by Autor (2015) and Goos and Manning (2007), who argue that routine tasks tend to be performed by middle-skilled employees.

I found that in the applying sector, jobs are newly created, transformed, and substituted in both developed and developing countries. Most of the substituted jobs are in developed countries. However, according to Vivarelli (2014), developing countries generally have an extensive applying sector, and unemployment induced by genome editing might have a more significant negative impact. On the other hand, the experts mention multiple traits that enhance the yield of a crop. This can result in a countervailing force: the productivity effect. This effect is more substantial in developing countries because it is expected that the yield increases in developing countries are relatively higher than in developed countries. Therefore, more agricultural labourers might be needed, which presses against the substitution effect of genome editing.

Furthermore, I found that the substituted jobs in developed countries are agricultural labourers who often come from developing countries. They work as seasonal employees in developed countries and often send remittances back to their home countries. This money is spent on education for children, housing, or starting small businesses back home (Martin, 2016). If their job becomes obsolete, this likely hamper development and work opportunities in the country the agricultural labourer originates from.

4.3.1 New jobs

Like in the making sector, the experts foresee jobs to be newly created in the applying sector. Two types of jobs are foreseen to emerge here: the urban farmer and farmers cultivating in places where no crops could grow before.

The first new type of occupation that experts foresee to emerge is the urban farmer. Three genome editing experts (10, 26, and 32) said this. The task that emerges due to genome editing is growing crops with niche traits indoors in an urban area. Because the urban farmer is expected to be engaged in many different tasks such as seeding, field management, and harvesting, a high level of adaptivity is required. Therefore, it is considered a manual, non-routinized task.

The experts say that genome editing allows for cultivating crops with specific niche traits, as these were too expensive to develop earlier. Because the market for such crops is small, not much arable land is needed to cultivate the crops. Therefore, urban citizens are expected to grow them in glasshouses in urban areas. Interviewee 26 (genome editing expert) describes it as follows:

> "They are urban citizens. (…) What things are on the market? What are the demands from the citizens? And then they produce those plants for them. And that may quickly go beyond of the conventional crop we are growing or envisioning".

The experts mentioned these urban farmers to emerge in cities in developed countries. Urban farming is rising in cities worldwide (De Bon et al., 2010), but the urban farmer that emerges because of genome editing is focusing on niche traits for a smaller market. Interviewee 26 (genome editing expert) mentions the urban farmer to engage in cultivating genome edited crops "to make some profit, or for fun". However, developing countries are concerned with more significant problems such as food security, and genome editing is thus used to "enable a problem-solving impact" (interviewee 26, genome editing expert). Therefore, the urban farmer focusing on niche traits is not likely to emerge in developing countries.

The second new job in the applying sector that the interviewees mentioned to be newly created is the farmer in areas where it was impossible to practice agriculture before. This was mentioned by seven interviewees, of which four were genome editing experts (Interviewee 3, 5, 8, 13, 22, 27, 31). The overall new emerging task is to cultivate crops in areas where it was not possible before. All smaller tasks that are needed for crop cultivation, such as seeding, harvesting, and field management, are emerging for this new type of farmer. These are routine tasks, which conflicts with existing literature arguing that jobs consisting of routine tasks become substituted instead of newly created (Autor, 2015).

Due to genome editing, it is possible to develop drought-resistant crops and cultivate them in dry areas or crops resistant to water in areas that cope with floods. Interviewee 31 (labour expert) explains this in the following example:

> "if you would use genome editing to cultivate crops on places where normally you would have a bad harvest, or no harvest at all. (…) In theory, it would then be possible to cultivate at places where now you could only hold animals, because it is too dry".

Another example is made by interviewee 22 (genome editing expert), who explains that a rice variant edited in a way that it can cope with salinity could allow farmers to settle in areas where before it was not possible to cultivate crops: "If you get a salinity tolerant variant, then in saline places or semi-coastal areas where they didn't grow rice (…) you can grow rice now".

All seven interviewees mentioned this job to emerge in developing countries, as these countries tend to be affected more by extreme conditions such as drought and floods. This might also be the reason that routine tasks lead to a newly created job. In developing countries, mainly smallholder farmers are engaged in agriculture and tasks such as seeding, field management, and harvesting are done manually by smallholder farmers themselves (Interviewee 4, genome editing expert). The farmer needs to shift between all those tasks, which requires situational adaptivity. This combination of tasks is considered a manual, non-routine task.

4.3.2 Transformed jobs

In addition to new jobs that emerge, the experts expect jobs to transform due to genome editing: the farmer and the agricultural labourer. The job of the farmer can be transformed in multiple ways.

First, the interviewees expect that the farmer's job will transform as they are expected to engage in a more sustainable way of agriculture. Genome editing is foreseen to reduce the need for agricultural chemicals such as pesticides, fungicides, and fertilizers. Half of the interviewees, both genome editing and labour experts, mentioned this (Interviewee 1, 5, 6, 10, 13, 17, 18, 20, 25, 27, 28, 29, 31, 32, 33). The experts mention that this will affect farmers in developed countries differently than in developing ones.

In developed countries, the farmers generally have agricultural labourers applying agricultural chemicals. Therefore, a reduced need for labourers who spray these chemicals is expected, meaning that the hiring practices of the farmers change. In addition, the task of buying a chemical for a specific disease is substituted. It is expected that farmers still purchase some chemicals, as there are many different chemicals for different purposes. However, the task of buying a chemical that targets a specific disease or fungi is substituted. Interviewee 27 (labour expert) explains how this as follows:

> "Farmers now use a lot of pesticides. There is a quite high use of pesticides in agriculture. And they also use fertilizers. So, what they go to their suppliers, and buy pesticides and fertilizers every year. Now gene editing comes in. So basically, they can have plants that are resistant to diseases. So, they don't need to have pesticides or fertilizers anymore of that type of disease".

In developing countries, the farmers themselves apply the chemicals. Thus, like farmers in developed countries, buying a specific chemical is substituted, but the task of applying them becomes substituted as well.

Second, the experts foresee the job of the farmer who will start producing genome edited herbicide tolerant crops to emerge. This results in genome editing to substitute the task of weeding. This was mentioned by two labour experts and one genome editing expert (Interviewee 21, 22, and 31). Genome editing can be used to develop crops that are herbicide tolerant. These crops are protected from weeds, as the herbicide kills the weeds but not the crop itself. Beforehand, the weed was manually removed. The interviewees mention seasonal labourers often do this task. For the farmer the task of hiring labour is substituted. "Earlier farmers were hiring labour for hand weeding. Now farmers start applying herbicide, and the weeds are controlled by herbicide, so they don't need labour" (Interviewee 21, labour expert). However, research shows that the farmer, especially the women farmers, are often involved in weeding as well (Daum et al., 2020; Gouse et al., 2016). By using herbicides, the time spent on weeding can reduce with 37 to 40 percent. This is quite significant considering that researchers found that weeding of rice in Sub-Saharan Africa can take up 250 to 278 hours per hectare (Ogwuike et al., 2014). Furthermore, the herbicide tolerant crops need to be sprayed with herbicides, which is a new task that the farmer is engaged in. Spraying herbicides is considered a routine task and thus is not in line with the notion that routine tasks usually decrease demand (Autor, 2015).

This transformation of the farmer's job is expected to happen in developing countries. "In developed countries, this question is mostly solved. I don't think people are manually removing weeds from major fields" (Interviewee 6, genome editing expert). That is because herbicide tolerant crops have already been developed in developed countries but not yet in developing countries. Genome editing is expected to be used to develop herbicide tolerant varieties for developing countries too. Because in developing countries the farmers themselves are spraying the crops with chemicals, it means that he or she would have an extra task. This might be the reason for a routinized task increasing in demand, as farmers in developing countries do not have the resources to invest in machinery that would automate the spraying of herbicides.

Third, experts foresee that genome editing can lead to a farmer starting to engage in more industrialized and precision agriculture. This was mentioned by more than half of the interviewees by both genome editing and labour experts (Interviewee 1, 5, 6, 10, 13, 17, 18, 20, 25, 27, 28, 29, 31, 32, 33). The tasks of a farmer will transform from managing a farm that is run by manual labour to managing a data driven farm. "We're seeing a movement away from the boots on the ground kind of labour, towards computer management (…) And so, I've heard farmers say things like, 'We've become data managers'" (Interviewee 23, labour expert). The new task that emerges, which is data management, requires technical expertise in data analytics. Therefore, it can be described as an abstract task. The task that becomes substituted is the management of agricultural workers. This can be described as an abstract task too, as management and communication skills are required (Autor, 2015).

The experts foresee that genome editing technologies will interact with the development of machinery that can be used in the field that goes in the direction of large-scale precision agriculture. This means that many farmers will move to more capital driven agricultural practices. Interviewee 23 (labour expert) explains that "it is going to promote and encourage precision agricultural systems that will likely rely far less on skilled agricultural labour and more so on technologies". An example of this is that due to genome editing, a crop's genome could be edited in a way that its leaves change in a particular colour when a specific condition, such as the crop not being adequately watered, is met. Genome editing might interact with sensor and automation technologies to manage crops in a 'smart' way. Interviewee 7 (genome editing expert) gives an example of this:

> "This might mean engineering certain traits that facilitate automation or that are well paired with automation of processes. Let's say automatic decision making about when to fertilize a crop, or when to give water to them, or when to harvest when the leaves or the fruits of a crop change"

This transformation of a farmer's job is expected to happen in developed countries. Here, the cost of labour is relatively expensive compared to the costs of machinery. There is thus more incentive to invest in this industrialized precision agriculture.

> "if labour is very cheap in that African country, why are you going to invest in a tractor, when you can have 100 guys on the job, and it is going to be much cheaper? So that's why you have agriculture being extremely mechanized in rich countries and very labour intensive in poor countries" (Interviewee 17, labour expert).

Fourth, the job of the farmer and the agricultural labourer transforms as it is expected that farmers will produce different crop species due to genome editing. Fourteen genome editing experts said this (Interviewee 2, 3, 4, 5, 7, 8, 12, 13, 16, 20, 25, 28, 30, 32). The way the job of the farmer and the agricultural labourer will be transformed depends on the type of new crop that will be grown, yet the changes involved in their jobs can be significant. Growing a different crop can mean that different types of equipment will need to be used, that seeding and harvesting periods change, and that they will supply to different markets. Each of these changes may require different tasks.

An example is that genome editing enables crops to grow at places where it was impossible to thrive in the local condition beforehand. Interviewee 13 (genome editing expert) mentions: "With technologies like CRISPR, it's more possible and plausible than ever that crops historically unattainable to the Dutch climate could be in play. Like chocolate, like coffee".

Furthermore, the interviewees expect farmers to start producing certain crops that can be made profitable using genome editing. For example, they often referred to orphan crops, which are crops that are referred to as “underutilized and neglected” (Tadele, 2019, p.678), and generally are not “optimized in a way like maize and wheat (…) which were bred for thousands of years” (Interviewee 4, genome editing expert). As a result, farmers could produce these crops profitably. Furthermore, because of genome editing, these crops can be optimized so that farmers want to cultivate them, as it results in a “better market condition. So, they build better qualities, and the market will be enlarged” (Interviewee 16, genome editing expert).

This transformation of the farmer’s and agricultural labourer’s job is expected to happen in developed and developing countries. Interviewee 7 (genome editing expert) gives the example of a market created for genome edited tomatoes that can be grown in the UK.

> “It might be that UK consumers prefer those tomatoes that are grown locally, rather than those that have a high environmental impact and transportation that are produced either in greenhouses in the UK or they’re produced in the fields in Spain, or Israel.”

This transformation is also seen in developing countries. The experts mentioned that crops that have not been optimized throughout the years, such as orphan crops, are often important for local communities in developing countries. Farmers in developing countries can shift to profitable cultivation of such crops because of genome editing.

Last, the interviewees expect the jobs of farmers and agricultural labourers to transform because genome editing can lead to changing cultivation times. Six experts mentioned this, both genome editing and labour experts (Interviewee 1, 10, 11, 17, 28, 29). In the future, it is expected that the cultivation time of crops will be edited so that the harvesting period lasts longer, or the culture time is shorter. For example, interviewee 1 (genome editing expert) says that you could “address traits where you can harvest earlier, and the harvest is stable for a longer time without rotting”. This has an impact on tasks around the production of a crop: the moment of seeding new crops, harvesting them, and the moment of interaction with actors in the supply chain. The nature of the tasks does not change, but the timeframe of the tasks does, hence it is transforming the job.

One aspect of this transformation is that labour is expected to become less seasonal. “You are not going to have peaks of harvesting (…). That is not going to affect the total amount of agricultural work, but it’s going to affect its seasonality” (Interviewee 17, labour expert). This results in transformed hiring practices: instead of hiring seasonal labourers for tasks as seeding and harvesting, the farmer is expected to hire fewer people but for a more extended period. This is expected to transform jobs in developed and developing countries. However, the experts mentioned that farmers are dealing with demand peaks for labour in both types of countries.

Multiple of the traits that are said to transform the job of the farmer and agricultural labourer are expected to increase the crop’s yield, such as herbicide tolerance, shortened culture time, and improvement of orphan crops. This leads to a productivity effect that generally increases the demand for labour (Acemoglu & Restrepo, 2018). The experts foresee this productivity effect is higher in developing countries than in developed ones. In developed countries, farmers have often adopted an industrialized way of agriculture. The increased yield will thus most likely be seeded, managed, and harvested by a more significant proportion of machinery. In developed countries, however, manual labour is still needed for this. Interviewee 31 (labour expert) gives the example of farmers in Africa who “will need more labour at the end of the season for harvesting when the yields increase”.

4.3.3 Substituted jobs

In the applying sector, the experts foresee three types of jobs to become substituted: agricultural labourers, processing labourers that select and separate crops, and smallholder farmers. These jobs become obsolete because genome editing replaces tasks performed by them.

As I discussed in the previous section on transformed jobs in the applying sector, there are various ways in which the farmer's job transforms because the farmer changes the way they practice agriculture. Multiple of these transformations cause a substitution effect for agricultural labourers. Four tasks performed by agricultural labourers are expected to become substituted: weeding, spraying chemicals, harvesting, and field management.

First, genome editing results in the agricultural labourer that performs the task of weeding becoming obsolete. This was mentioned by four labour experts and one genome editing expert (Interviewee 5, 14, 21, 22, 23). This task is characterized as a routine task, for which a low level of skills is needed. This partly contradicts what Autor (2015) argues. He stresses that middle-skilled employees often perform routine jobs.

This job is mainly situated in developing countries where “farmers are hiring labour for hand weeding” (Interviewee 21, labour expert). Manual weeding in developed countries is a task that is not frequently performed nowadays. That is because in developed countries, weed management is done either by chemical herbicides or by machinery. Chemical herbicides have not been widely used in developing countries (Shaner & Beckie, 2014)(Shaner & Beckie, 2014), and “these machines individual farmers cannot afford, because most of smallholder farmers are poor” (Interviewee 21, labour expert).

A second task that is substituted due to genome editing is spraying chemicals such as pesticides and fungicides. This was mentioned by seven experts, both genome editing and labour experts (Interviewee 6, 18, 21, 25, 26, 31, 32). However, spraying pesticides is also characterized as a routine task for which a low level of skills is needed and is thus also partially contradicting literature on job types that are substituted (Autor, 2015).

This job is expected to be in developed countries. There, spraying pesticides is “a service which farmers buy” (Interviewee 6, genome editing expert), whereas, in developing countries, the spraying is done by the farmers themselves, hence transforming their job.

A third task that experts foresee to be substituted by genome editing is the harvesting of crops. This is mentioned by fourteen interviewees, both genome editing and labour experts (Interviewee 3, 4, 5, 6, 7, 10, 11, 14, 23, 25, 28, 31, 32, 33). They expect this task to become obsolete because genome editing can foster automatized agricultural processes, such as harvesting crops. Harvesting is a routinized job for which a low skill level is sufficient. Interviewee 3 (genome editing expert) gives the following example: "You can change plants' architecture to enable easier harvesting (…) which gives us the ability to harvest the plants mechanically."

A fourth task that is expected to be substituted by genome editing is also due to a shift towards automation of agriculture. Seven interviewees, both genome editing and labour experts, foresee the task of field management to become substituted (Interviewee 5, 7, 10, 11, 14, 16, 23). Field management concerns ensuring that the crop grows well by, for example, watering and fertilizing it. Like the other three tasks of the agricultural labourer, this task is a routine one for which a low skill level is sufficient. Interviewee 7 (genome editing expert) explains how genome editing substitutes the task of field management:

> "I know that there is a lot of efforts nowadays in especially fully developed countries to implement vertical farming and automation of farming process (…) by automatic decision making about when to fertilize a crop, or when to give water to them (…) when either the leaves or the fruits of a crop change in colour".

This changing colour of either the leaves or the fruits when a condition is met can be engineered by genome editing.

Experts foresee that both harvesting as well as field management, are tasks that are substituting agricultural labourers predominantly in developed countries. Labour is relatively expensive compared to the costs of machinery in developed countries. For example, in the Netherlands, "labourers are just super expensive" (Interviewee 25, genome editing expert). The experts do not expect this to happen in developing countries, because "the labour costs are low and there are many people who want to do the work" (Interviewee 32, genome editing expert). Whereas the job that becomes obsolete has a higher chance of being situated in a developed country, multiple experts indicated that these jobs are operated by people from developing countries (interviewee 25,32,33). Many seasonal labourers in Europe come from countries in Eastern Europe, for example.

A second job that is expected to be substituted is the processing employee who selects and separates crops in the processing phase. Four genome editing experts mentioned this because of genome editing (Interviewee 7, 8, 28, 32). The reason for this is that genome editing can make crops more uniform and design them in a way that they are easier to process. Therefore, genome editing substitutes the task of selecting and separating the crops for different uses. Again, this is a routinized task for which a low skill level is needed. This is not in line with Autor (2015), who suggests that mostly routinized middle-skilled jobs are likely to be substituted.

Interviewee 7 (genome editing expert) tells an example of tomatoes that need to be selected for different purposes: "Tomatoes are used directly as tomatoes, but also to produce sauce or to produce ketchup. Maybe such differentiation might be also helped by genome editing by making the quality of the fruits more uniform". Generally, the tomatoes that fit certain standard are transported to the supermarket, whereas the ones that do not fulfil all quality standards are used for products as ketchup. The selection step can thus be skipped due to genome editing by developing uniform products.

The interviewees did not elaborate on the type of country in which the processing employee is likely to be situated. However, Barret (2008) says that the processing sector is strong in developed countries, but also processing activities in developing countries have risen since the 1990s. Before food processing existed on a small scale, sometimes within a household, but since the end of the last century, significant investments have been made in agri-food processing for retail stores and restaurants in developing countries (Barrett & Mutambatsere, 2008; Reardon & Barrett, 2000). Therefore, it is expected that the job of the processing labourer could be substituted in both developed and developing countries.

The last type of job that experts expect to become obsolete is the job of the smallholder farmer. This was mentioned by three interviewees, of whom two were labour experts (Interviewee 9, 23, 24). These experts foresee that genome editing has a significant chance of being used in a system characterized by large-scale agriculture. The job of the smallholder farmer does not become obsolete because technology takes over specific tasks, but because the prevailing system pushes the smallholder farmer out of business. Interviewee 9 (genome editing expert) explains that this is caused by dependencies that are created on the large agricultural multinationals:

> "This genetic engineering is patented by a small number of companies. They are dominating the market. So, they provide genetically modified seeds at a relatively cheap price to the smallholder farmer. They are growing fast, and they produce really good quality crops, so they are satisfied, and then what? They increase the price. (…) So, for the short term, it is probably good. But (in the) long term, the small farmers' business will go down".

The smallholder farmer is mostly situated in developing countries; hence the substitution effect will be more significant there. In developed countries, agriculture is for a large part industrialized already. "Most developing countries still have a huge amount of smallholder farmers, compared to here, where we have more the industrial agriculture" (Interviewee 4, genome editing expert).

However, literature contradicts the expectation that smallholder farmers become obsolete due to an industrialized agricultural system fostered by genome editing. Several authors point at factors that would put pressure on smallholder farmers, such as land alienation (Vanlauwe et al., 2014), unfair crop prices (Sitko & Chamberlin, 2015), and competition from industrial farmers (Diao & Hazell, 2020). It was claimed that smallholder farmers were likely to be pushed out of the market by intensified, large scale farming. However, the opposite turned out to be true. Empirical data showed that the farm size in a developing country only decreased, meaning a shift towards more small-scale agriculture (Lowder et al., 2016; Ma & Sexton, 2021). It thus remains unclear if genome editing will lead to a substitution of the smallholder farmer, as other pressures that have been thought to substitute this form as farming have not succeeded in it.

4.4 Complementary sector

The complementary sector consists of the type of jobs that facilitate or hamper the use of genome editing as well as the use of genome edited crops. These jobs are thus not directly involved in de development of genome editing and genome edited crops, nor are they concerned with cultivating them. However, they can either stimulate or hold back the development and use of crop genome editing.

My main finding is that in complementary sectors, the experts foresee mainly jobs to be transformed, one job to be newly created, and an entire sector to shrink in terms of employment. Seven experts foresee the job of the developer of high-tech agricultural equipment to emerge. His or her task will be to develop machinery that combines the possibilities of genome edited crops with automation technologies.

Twenty-four of the 33 interviewees expect jobs to transform in the complimentary sector. They expect more jobs to transform in the complementary sector than in the other two sectors. Five transformed jobs are expected because genome editing creates new tasks for existing occupations.

First, they mentioned the job of the policy developer to transform because he or she will have to learn how genome editing works and develop a new regulatory framework. Second, the job of the compliance employee changes. Tasks emerge that concern the approval of crops that breeding organizations send in to be approved for market use and checking if no foreign DNA or off-target effects are present in the crop. Third, it is expected that the job of the legal consultant will transform as the task emerges to provide legal guidance to companies who want to bring a genome edited crop to the market. Fourth, it is expected that the job of university teachers in plant sciences will change, as they will teach this new technology to students. The last job that is expected to transform is in the transporting sector. Because genome editing is enables to grow more varieties of crops locally, transporters will have shorter distances to cover.

Furthermore, the experts foresee that the agrochemical industry will shrink due to the introduction of genome edited crops, which eight experts said. This is not because genome editing affects tasks performed by the workers but because of a shift in agricultural practices.

The experts mentioned that jobs are newly created and transformed because of the emergence of new tasks. All new tasks that emerge require a high level of technical expertise and can therefore be characterized as abstract, non-routine tasks. As literature has shown, technological innovation generally increases demand for such jobs (Autor, 2015; Goos & Manning, 2007). Within the complementary sectors, the experts did not mention genome editing to substitute any tasks.

The interviewees expect that the developer of high-tech agricultural equipment, the newly created job, will be situated in developed countries. This job requires the development of technological machinery, and it thus follows what literature has said about the type of country where technological developments occur (Vermeulen et al., 2018). However, I found that jobs are expected to transform in complementary sectors and could become substituted in both developed and developing countries. To the best of my knowledge, in the literature on labour implications of technologies, the complementary sectors of developing countries were outside of the scope (Vermeulen et al., 2018). Therefore, my finding that jobs in complementary sectors in developing countries are expected to be affected by genome editing is a novel insight within the research about technology induced labour implications.

4.4.1 New jobs

Compared to the making and applying sector, the experts foresee less jobs to be newly created in complementary sectors. Only one occupation has been mentioned to emerge: developers of high-tech agricultural equipment. Eight interviewees mentioned this new type of job to emerge. Seven genome editing experts and one labour expert said this (Interviewee 3, 4, 6, 7, 9, 26, 28, 33). The task of this developer will be to build machines that combine agricultural automation with genome editing possibilities. Because of the high expertise needed for this task, it is considered an abstract task.

The interviewees expect many developments that will steer agriculture in a precision-oriented and automated direction. Interviewee 33 (labour expert) gives the example of combining genome editing with information technology: "We have another innovation which is rapidly advancing: Information Technology. That is data-driven agriculture with all sorts of sensing and precision applications. (…) I thus see a strong interaction with Information Technology". Another example is given by interviewee 28 (Genome editing expert), who explains that strawberries ripe in different stages, hence they need to be manually picked. By editing them in a way that they ripe simultaneously, they can be mechanically harvested. The developers must make the machines to harvest the strawberries of high-tech agricultural equipment. Hence these tasks are emerging because of the possibilities that genome editing brings.

The interviewees expect this job to emerge in developed countries because the high-tech sector is more developed in these countries. "This kind of equipment is generally developed in rich countries. I do not think that this is actually happening in developing countries" (interviewee 19, genome editing expert).

4.4.2 Transformed jobs

Whereas the experts expect one new job type to emerge, multiple jobs are expected to be transformed. In total, five job types were said to transform: The policy developer who creates the regulatory framework for genome edited crops, the job of the compliance employee, the legal consultant, transporters of crops, and university teachers in plant science.

The first job that the interviewees mentioned to be transformed is the job of the policy developers working within the government's regulatory agencies. This was mentioned by almost half of the interviewees, of whom two were labour experts (Interviewee 1, 2, 3, 5, 6, 7, 9, 12, 13, 14, 16, 26, 27, 29, 32). These policy developers have worked on GMO regulations before and will now create regulatory frameworks for genome edited crops. They are expected to learn how genome editing works to create policies and keep up to date with these fast-evolving technologies. Thus, a continuous learning process on genome editing is needed, which would be a new task for these policy developers: "the government officials are learning with us" (Interviewee 6, genome editing expert). Another task is to design a compliance framework of how genome edited crops must be regulated. The experts foresee that a more product-oriented regulatory framework will likely be adopted if genome editing is allowed in a country. Producers can send in a product on a case-by-case basis to see if it is regulated or not. The task that emerges for these policymakers is thus to design this framework.

This job is expected to transform in developed as well as developing countries. The transformation of this job depends on the regulatory acceptance and not the level of development. If genome editing is not seen as a GMO technique, new regulations will be set. If this does not happen, which is the case in Europe, the experts did not mention that these jobs will transform.

A second job that will transform, according to the interviewees, is the job of the people that monitor the compliance framework. This means that this job is only expected to transform in the case of a shift in the regulatory framework and is thus dependent on the transformation of the policy making job. This transformed job has been mentioned by fourteen interviewees, both genome editing and labour experts (Interviewee 1, 5, 7 , 9, 11, 12, 13, 14, 16, 22, 26, 28, 29, 32). A new task for these compliance employees is to determine if and how the crop is regulated based on the newly set regulatory framework. It is expected that seed producers that produce genome edited crops will have to send in a detailed dossier with information about how the crop is produced: "which changes you made" and "information about the elements that were used" (Interviewee 32, genome editing experts). Because of a combination of legal expertise and molecular biology knowledge required to determine if a crop is regulated, this task is considered an abstract, non-routine task.

A new task is to conduct a test to check whether foreign DNA is added or if any off-target effects occurred that might potentially be dangerous. According to the interviewees, this testing will be done by sequencing the crop's DNA to test whether no foreign DNA is there (Interviewee 7). Interviewee 2 explains that sequencing can also be used to "make sure no off-target mutation was introduced". Interviewee 16 explains that this process will go as follows: "They get the DNA, and they do genome sequencing. And if they can run a computer program to see if there is any unknown DNA integrated into a plant genome. And if this happens, we couldn't treat this as a gene editing crop: it is a GMO. If it is totally free of foreign DNA, we can say it is a gene edited crop, and it should be safe to the environment". Because of the technical knowledge about molecular biology, this task is considered an abstract, non-routine task.

As with the policy developer, the compliance employee is expected to be situated in both developed and developing countries, depending on the regulatory acceptance of genome edited crops.

The third type of job that is expected to transform is the job of the legal consultant that guides organizations on bringing their crop to the market. This was mentioned by four genome editing experts (Interviewee 13, 20, 29, 32). An emerging task for these consultants is to help companies to get their crops to the market. Interviewee 29 (genome editing expert) explains that these people "help that company to adhere to the regulations and to produce the dossiers that are necessary to get something approved". In addition, according to Interviewee 13 (genome editing expert), they will help organizations with "IP and licensing".

These consultants were already advising companies regarding GMO products. They do expect that now smaller companies can be clients if they can also start producing genome edited crops. "When those matters (genome editing) will also be accessible for small and middle-large companies, they will guide them on the regulatory path which would also exist for their crops". The tasks of these people will change because of the supposed differences in regulations compared to GMOs. The experts foresee that these people will have to acquire technical knowledge about genome editing. It can also be that genome editing experts are trained to become law experts “because the people in the regulatory area don’t understand gene editing. So, they must employ the scientists into their workforce for regulatory matters too” (Interviewee 20, genome editing expert).

It is expected that these consultants work in developed and in developing countries, as breeding organizations need a consultant that is familiar with local regulations.

Fourth, also jobs in transporting crops are expected to change. This was mentioned by four genome editing experts (Interviewee 1, 7, 25, 26). They expect the routes from the land to the consumer will be shortened because of the ability to grow a wider variety of crops locally. The tasks that emerge and become substituted depend on which crop will be grown where and how this affects the existing transportation system.

Interviewee 26 mentioned as an example that lettuce is usually grown on the East coast of the USA and must be transported in trucks throughout the rest of the country. If genome editing is used for traits that enable farmers to grow lettuce elsewhere in the USA, too, then the crop can be grown more locally. These large distances can be shortened.

This transformation is expected to happen mostly in developed countries. In developing countries, it is more often the case that consumers eat crops that are grown locally. As interviewee 26 (genome editing expert) says: “people in developing countries don’t have the luxury to choose where their dinner comes from”.

A fifth job that is foreseen to transform is the job of university teachers that teach in plant breeding. Six interviewees said this, of whom one was a labour expert (Interviewee 9, 10, 12, 15, 25, 28). The job of these teachers transforms because of emerging tasks. First, they will teach a different tool to students. “You could see it really having a substantial change, bringing that in and actually teach it” (Interviewee 10).

Additionally, the experts foresee the plant breeding department to grow, as they expect students will find the study more interesting because of genome editing being taught. The job of the university teacher will change because more students will enrol. This is not a new or substituted task but an existing task that changes in quantity. “I believe in the university setting probably more people are going to some department offering genetic engineering” (Interviewee 12, genome editing expert). Interviewee 25 (genome editing expert) expects this too and says that “If gene editing is allowed, more students will go in the direction of plant breeding. I can imagine that some people might think plants and plant breeding is a boring field, but if gene editing is allowed, it leaves a lot more to the imagination”.

The job of university teachers is expected to transform both in developed as well as in developing countries. It is expected that many university labs worldwide will adopt genome editing in their teaching programs because of its cost-effectiveness and ease. Interviewee 13 (genome editing expert) talks about university labs being set up in countries in South America, Southeast Asia, and, albeit not a lot, in Africa.

4.4.3 Substituted jobs

In addition to one newly created job and multiple transformed jobs in complementary sectors, the experts expect that jobs in only one sector within the range of complementary sectors are expected to be substituted: jobs within the agrochemical industry. This was mentioned by one-fourth of the interviewees, both genome editing and labour experts.

In contrast to the substituted jobs in other sectors, here the experts argue that the whole sector will shrink. Eight interviewees said this, both genome editing and labour experts (Interviewee 6,7,8, 14,25,26,27,31). These interviewees foresee that when genome editing is widely used in crops to increase their resistance against pests, fungi, and insects, or decrease their need for nutrients provided by fertilizers, jobs across the board become obsolete. Interviewee 6 (genome editing expert) explains this as follows:

> "Will it completely remove all these jobs associated with the development and production and distribution of chemicals? No. But I can say that it probably will reduce the number of jobs associated with those things. Now we must develop chemicals for let's say, 100 different pests which attack our crops in the field. In the future, this will be reducing".

Interviewee 26 (genome editing expert) gave the example of crops that can be edited so they can fix nitrogen themselves and do not need as much fertilizer anymore:

> "You don't really require as much of fertilizer for this kind of crop because they can do that themselves. Why would they need fertilizer? If we solve the problem and we don't require any fertilizers: think about the fertilizer industry. Think about marketing, the store selling fertilizer".

It is thus expected that not a specific job will be substituted, but it will "most likely result in a lower number of people who will be employed within the industry" (Interviewee 27, labour expert).

Agrochemicals are used in both developed and developing countries. The agrochemical industry has been prominent in developed countries for a longer time than in developing countries. However, in developed countries, the use of agrochemicals has decreased the last few years, whereas, in developing countries, the opposite is happening (Zhang, 2018). Genome editing is expected to reverse the trend in developing countries and strengthen the trend in developed countries, leading to jobs in both types of countries shrinking in demand.

5. Conclusion

Genome editing technologies are highly promising for crop breeding. Because of their speed, precision, and cost-effectiveness, genome editing technologies make it possible to develop traits that previously would not have been possible or would have taken significantly longer to implement in the crop. In addition, academics have studied the environmental and societal implications of these far-reaching technologies (e.g., Baltes et al., 2017; Bartkowski et al., 2018; Jasanoff et al., 2015; Lassoued et al., 2019). Concretely, research revealed many benefits and risks of using genome editing in crop breeding.

Remarkably, however, one important societal implication of genome editing technologies has not been researched yet: its labour implications. Other far-reaching technologies, such as automation and digitalization, have been found to have profound labour implications. Moreover, while there are several indications that also genome editing may affect jobs, it remains unclear whether and how these technologies will impact labour. Therefore, this research aimed at unveiling the labour implications of genome editing technologies used in crops. This was done by answering the following research question:

> What labour implications do experts expect to occur due to crop genome editing?

To answer this question, 33 interviews were held with 23 genome editing experts and ten labour experts from both developed and developing countries.

My main finding deriving from these interviews is that experts expect genome editing to have a wide range of labour implications and that these labour implications can profoundly impact labourers around the world. Genome editing technologies are expected to have very diverse implications. It is expected that it will create new jobs, transform existing jobs, and make certain jobs obsolete. The results regarding how jobs are impacted are summarized in Table 7,8 and 9.

The experts foresee new jobs to emerge in all three sectors. Most new jobs could emerge in the making sector, such as the bioinformatician whose task will be to unveil a crop's genetic function. In the applying sector, two jobs emerge: the urban farmer who will produce niche crops indoors in urban areas and the farmer who starts cultivating crops at places where this was not possible before. Additionally, one new job is expected to arise in the complementary sectors: the agricultural machinery developer who combines genome editing and automation technologies. An extensive overview of the jobs expected to be newly created can be found in Table 7.

Table 7: New jobs in the making, applying, and complementary sectors due to crop genome editing.

Making sector			**Applying sector**			**Complementary sector**		
Job description	Tasks	Developed/ Developing country	Job description	Tasks	Developed/ Developing country	Job description	Tasks	Developed/ Developing country
Bioinformatician	(+) Discovering genetic functions of crops	Developed and developing countries	Urban farmer	(+) Grow crops with niche traits indoors in urban areas	Developed countries	Developer of high-tech agricultural equipment	(+) Develop machinery that combines genome editing with automation technologies	Developed countries
Genome sequencer	(+) Mapping the genomic sequence of a crop	Developed and developing countries	Farmer	(+) Cultivating crops in areas where no agriculture was possible before	Developing countries			
Scientist developing genome editing technologies	(+) Develop genome editing systems that are more precise and effective	Developed and developing countries						
Genome editor	(+) Modifying the crop's genome	Developed and developing countries						

Jobs that transform due to genome editing are also expected to transform across the board. In the making sector, for example, the job of the breeder is expected to transform. He or she could move from the field to the lab since the task of crossing and backcrossing is substituted due to the ability to implement genetic modification by genome editing precisely. In the applying sector, the job of the farmer and the agricultural labourer could transform in multiple ways. For example, the farmer can decide to produce crops that could not be cultivated in the local environment before, such as cultivating coffee in the Netherlands. This possibility will affect how the farmer and agricultural labourer engage in agricultural practices. Moreover, most jobs are expected to be transformed in the complementary sectors. For example, the experts mentioned the policy maker's job to transform, as they need to get acquainted with how genome editing works and build a new regulatory framework. An extensive overview of the jobs that are expected to transform can be found in Table 8.

Table 8: Transformed jobs in the making, applying, and complementary sectors due to crop genome editing.

Making sector			Applying sector			Complementary sector		
Job description	**Tasks**	**Developed/ Developing country**	**Job description**	**Tasks**	**Developed/ Developing country**	**Job description**	**Tasks**	**Developed/ Developing country**
Breeder	(+) Modify the genome of a crop (-) Cross and backcross crops to get the desired variety	Developed and developing countries	Farmer[3]	(+) Engaging in a more sustainable way of agriculture (+) Producing herbicide tolerant crops (+) Engaging in industrialized precision agriculture (+) Producing crops with different culture times (+) Cultivating different crop species	Developed and developing countries Developing countries Developed countries Developed and developing countries Developed and developing countries	Policy developer	(+) Continuously learn about genome editing (+) Develop a product based regulatory framework	Developed and developing countries
Scientist doing fundamental research	(+) Using genome editing to investigate molecular systems of plants	Developed and developing countries				Compliance employee	(+) Decide for approval of genome edited crops (+) Sequence crop to check for foreign DNA or off-target effect	Developed and developing countries
Marketeer of genome edited crops	(+) Communicate the advantages in a consumer-oriented way (-) Communicate message associated with industrial agriculture	Developed countries				Legal consultant	(+) Help breeding organizations to bring their genome edited crop to the market	Developed and developing countries
			Agricultural labourer cultivating different crop species	Tasks transform depending on which crops will be produced	Developed and developing countries	Transporters	Tasks change depending on the transportation system. Less distances are covered	Developed countries
						University teachers	(+) Teach genome editing	Developed and developing countries

The experts foresee jobs to become obsolete in the applying and complementary sectors, but not in the making sector. In the applying sector, most jobs are expected to be substituted due to genome editing. For example, experts foresee the agricultural labourer performing the task of spraying chemicals becoming obsolete. Furthermore, the experts foresee the whole agrochemical industry to shrink. Jobs in this industry, such as salespersons and developers of pesticides, are expected to become obsolete. However, jobs were not specified in terms of tasks. An extensive overview of which jobs are expected to be substituted can be found in Table 9.

[3] To keep the table of the expected transformed jobs as brief and comprehensive as possible, I summarized the tasks of the farmers. There are many tasks that can affect farmers. Table 10, which summarizes all tasks per type of farmer, can be found in Appendix E

Table 9: Substituted jobs in the applying and complementary sectors due to crop genome editing

Applying sector			**Complementary sector**		
Job description	Tasks	Developed/ Developing country	Job description	Tasks	Developed/ Developing country
Agricultural labourer	(-) Spraying chemicals (-) Harvesting (-) Field management (-) Weeding	Developed countries Developed countries Developed countries Developing countries	The agrochemical sector is expected to shrink	No specific tasks were identified	Developed and developing countries
Processing labourer	(-) Selecting and separating crops	Developed and developing countries			
Smallholder farmer	Is pushed out of practice due to neoliberal agricultural system	Developing countries			

The results of this thesis are both new and relevant for academia. My findings are novel because no research has focused on the labour implications of genome editing before. I showed that it is expected that these technologies have far-reaching labour implications for labourers worldwide.

In addition, I found that jobs in the complementary sectors in developing countries are expected to transform and become substituted. Hence, these findings contribute to the body of literature as research has not explicitly focused on the labour implications of technological innovation in complementary sectors of developing sectors yet.

Furthermore, the labour implications of genome editing were studied ex-ante. Whereas most research focuses on studying the effects on jobs of far-reaching technologies ex-post, I showed that studying the future labour implications are helpful for providing an overview of how jobs might be affected due to technologies. However, to accurately measure the gravity of the labour implications of crop genome editing in real life, it is essential to keep monitoring those.

In addition to the novelty of my findings, my research is relevant to society and policymakers. Genome editing is foreseen to create employment and opportunities for some while creating unemployment for others, with potentially significant implications for inequality. Society can benefit from these ex-ante results as anticipatory policy strategies can be developed aiming to mitigate the potential disrupting effects and enhance the beneficial labour effects of crop genome editing.

Lastly, my findings provide additional relevance to society as they demonstrate that labour implications should be considered when discussing how genome editing can best be governed. Currently, only environmental and societal implications such as health, economic, and ethical implications are considered. If the labour implications of genome editing are recognized too, a better-informed debate on how to govern the technology can be ensured.

6. Discussion

In this section, I will discuss the findings in the light of literature on technology induced labour implications, reflect on the framework I use, and consider the labour implications of genome editing in relation to other implications of the technology. In addition, limitations of the study will be provided. Finally, I will end with recommendations for further research.

6.1 The results in a broader perspective

This thesis shows that genome editing experts and labour experts expect many ways in which jobs are affected due to crop genome editing. How does this compare to what has been found in the literature on other emerging technologies?

This research indicates that genome editing is expected to lead to multiple jobs being newly created, transformed, and become obsolete. Most newly created jobs can be allocated to the making sectors, most substituted transformed jobs to the complementary sectors, and most substituted jobs to the applying sector. This corresponds with earlier findings on the labour implications of automation and digitalization technologies (Brougham & Haar, 2020; Dachs, 2018; Vermeulen et al., 2018). Vermeulen et al. (2018) argue that the initial labour substitution effect that occurs mainly in the applying sector is offset by new and transformed jobs that embrace technological innovation. This effect can be predominantly observed in the making and complementary sectors, and to a lesser extent, also in the applying sector.

My findings show that the labour-saving effect of genome editing technologies is compensated by many jobs created and by jobs transformed to reap the complementarities of genome editing. It is not possible to argue that based on my findings, the increased demand for new and transformed jobs may be higher than the decreased demand for substituted jobs, as the effect could not be quantified. However, the fact that the experts foresee multiple jobs to be created and transformed across the three sectors seems promising. Research shows that on an aggregate level, technological innovation results in an increase in demand for new and transformed jobs that is relatively higher than the decrease in demand for jobs that are substituted, leading to an overall rise in the number of jobs (Acemoglu & Restrepo, 2018; Autor, 2015). Therefore, as a similar trend could be observed for genome editing, it might lead to a net increase in jobs.

On the level of workers, genome editing might increase inequality between labourers. I found that most obsolete jobs are expected to occur in the applying sector and that routine tasks performed by low-skilled workers characterize those jobs. Most jobs that are created consist of non-routine tasks that require a high level of expertise. The former finding deviates from literature that argues that substituted jobs generally are characterized by a great extent of routine tasks performed by middle-skilled workers, such as bookkeepers and salespersons (Autor, 2015). Middle-skilled workers are reinstated in the labour market more quickly than lower-skilled workers, as they can often perform the tasks of lower-skilled positions, and be easier trained to perform higher-skilled work (Autor, 2015; Goos et al., 2014; Goos & Manning, 2007). Therefore, the lower-skilled workers face the highest risk of unemployment, as they cannot quickly be reinstated in the labour market (Bessen, 2017; Peters et al., 2019). Moreover, this could increase inequality as the demand for lowly skilled workers will decrease, resulting in lower wages (Autor, 2015; Goos, 2018; Peters et al., 2019). This is expected to be the case regarding genome editing, as those workers of positions that become obsolete are unlikely to be reinstated in newly created jobs.

Based on this result, it is important to find ways to reinstate those people whose jobs might become obsolete due to genome editing in crops. Research shows that there are numerous ways to reorchestrate the labour market when it is disrupted by technology. Education is frequently mentioned as a key driver to enhance the reinstatement of workers (Gaponenko & Glenn, 2020; Stevens & Marchant, 2017). This would require a restructuring of the educational system, as research shows that many skills needed in the renewed labour market are not taught in educational programs (Bessen, 2014, 2017). However, changing the educational system is a long-term approach that is less likely to benefit the workers that face direct substitution due to genome editing. Short-term solutions could be policies tackling the attractiveness for employers to hire workers by imposing tax benefits (Gaponenko & Glenn, 2020), employment sharing among multiple workers, or jobs created by the government, such as infrastructure restoration or assistance to elderly people (Stevens & Marchant, 2017). It is evident that scientists and policymakers should focus on formulating a strategy or combination of strategies that will help workers be reinstated who are negatively affected by genome editing.

However, concerning potential positive effects on a country level, genome editing might increase equality, as it offers opportunities for developing countries. My findings show that it is expected that genome editing as a technology as well as genome edited crops have a high chance of also being developed in developing countries. This may result in the creation of new jobs as well as transformed jobs in the making sector of developing countries. This finding shows that genome editing could create labour opportunities in the making sector of developing countries. Cirera and Sabetti (2019) argue that if innovation is set within a developing country, this country's making sector will experience a rapid growth that is relatively larger than in developed countries. Moreover, the further the developing country is from the technological frontier, the higher the rise in demand for labour in the making sector will be.

Consequently, this finding indicates that genome editing is expected to result in opportunities that might contribute to increasing equality between developing and developed countries. Therefore, to accelerate closing the technological innovation gap between those countries, the policies should be developed so that access to genome editing for developing countries is ensured. Nevertheless, if access to developing the technologies is provided, this does not automatically mean that the gap will be closed. There might, for example, still be a shortage of labourers that can execute those tasks required in developing countries, resulting in the making and use of genome editing technologies in developed countries.

Besides comparing my results to other labour implications found in literature, it is important to reflect upon the framework developed by Vermeulen et al. (2018) that I used. This framework proved to be a valuable lens to create a comprehensive overview of the affected jobs and sectors. I found that many of the individual effects that genome editing is expected to have on jobs are caused by, or are causing, impact on other jobs, sometimes in other sectors too. This highlights the interrelations between employment in the same or in different sectors. Therefore, when considering which path to take when developing genome editing technologies, making policies, or regulating genome editing and genome edited crops, we should not solely focus on the labour implications within the genome editing field, which would be the making sector. Instead, a multisectoral approach must be adopted by also considering how labour is impacted in the applying and complementary sectors to ensure an inclusive approach.

In addition, I adapted this task-based multisectoral framework of Vermeulen et al. (2018) by including whether the job impact was expected in developed and/or developing countries. This proved to be valuable because genome editing is expected to have different labour implications depending on the type of country. Therefore, to get a complete grasp of the labour implications of a technology, researchers should combine a multisectoral approach with the distinction between developed and developing countries. Moreover, when considering the right pathway for genome editing, policies and regulations should not focus on developed countries only but account for differences between countries' development levels.

Furthermore, it is important to relate the results to the environmental and societal implications of genome editing that have been addressed in literature so far: health, governance, economic, and ethical implications. These implications have been thoroughly described in the literature, but the labour implications that genome editing might cause have been completely ignored. I found that genome editing is not only expected to have significant effects on jobs, but also that the labour effects interrelate with other environmental and societal implications. For example, the governance implications of genome editing play a vital role in the agricultural system that will prevail (Bartkowski et al., 2018; Jasanoff et al., 2015). This, in turn, influences the labour implications of genome editing, as I found that the prevailing agricultural system acts as a conditional factor. In turn, the expected labour implications could play a role in the discussion on responsible governance of genome editing technologies, as they are expected to affect many workers across the globe.

Therefore, a holistic approach should be adopted when considering the societal implications of genome editing, in which the labour implications are to be included. However, this holistic approach that would examine the impact of genome editing on society as a whole has not been brought up in research. Instead, societal implications have been predominantly studied in isolation from each other (Bartkowski et al., 2018; Hartley et al., 2016).

A starting point for such a holistic approach could, for example, be to use concepts derived from the balanced scorecard. Bannister and Remenyi (2003) used this balanced scorecard approach to present a framework to evaluate an extensive range of societal implications of Information and Communication Technologies (ICT). The balanced scorecard is a holistic tool for business strategy evaluation developed by Kaplan and Norton (1992). The framework on the societal implications only incorporated a few aspects of the balanced scorecard, namely the benefits and disbenefits and how to measure them. Despite that this resulted in a very simplified overview of the positive and negative societal implications of ICT, it succeeded in a holistic approach and refrained from studying societal implications in isolation from each other. Such an approach could be an initial step in identifying the impact of genome editing on society as a whole.

6.2 Limitations

Even though substantial efforts have been made to conduct this research as systematically and academically sound as possible, still some limitations must be pointed out.

Bryman (2016) identifies three quality criteria for research. First, reliability, which is assured by conducting 33 interviews to minimize outliers affecting the results. Second, replicability, which is enhanced by providing the selection criteria for experts, the steps taken to retrieve the sample, the interview guide, and the coding framework. Third, validity, which refers to the how accurate the conclusion is. The validity of this study could be enhanced by triangulation of data, or by conducting all interviews by more interviewers, which I did not do in this thesis (Bryman, 2016).

Furthermore, the sample of interviewees included experts from developing countries. However, all experts from developing countries were affiliated with organizations in East or Southeast Asia. Thereby, experts from developing countries in Africa or Latin and South America were absent. I found that the labour implications differ depending on the crops that are cultivated. The cultivated crop is assumed to be different in South America compared to East Asia, for example. Therefore, the findings could have been richer if labour implications from developing countries in more parts of the world would be provided, limiting this study's eventual results.

In addition, specific background knowledge about an occupation is often needed to comprehend why a job is expected to emerge, transform, or become obsolete. Unfortunately, the experts did not always have this specific knowledge. For example, the experts indicated that the lab worker who maps the genomic sequence of a crop’s DNA is a job that is likely to emerge but could not elaborate on the specific tasks they might be doing. To mitigate this shortcoming, I consulted literature about this job. However, it would have been more valuable to interview people working in the field of Next Generation Sequencing.

Last, I showed that genome editing technologies are expected to have many diverse labour implications. My findings provide a comprehensive overview of expected labour implications. Still, they do not specify which implications are more probable to happen, nor which labour implications are likely to have a more significant effect on the number of jobs affected. This limits how my findings can contribute to decision-making concerning the best strategy regarding genome editing technologies.

6.3 Recommendations for future research

The findings on the expected labour implications of genome editing in crops lay the basis for recommendations for future research.

First, a longitude study is necessary to track the labour developments in the making, applying, and complementary sectors over a longer period of time. In this thesis, I gave initial findings that indicate what experts in the field expect to happen in terms of labour implications. These findings should be tracked in real life to identify how jobs are affected and which effects are more significant than others.

Second, future research could develop efficient strategies to mitigate job losses that are expected due to genome editing. I found that experts foresee multiple jobs to become obsolete. To counter technological unemployment, it is crucial to understand how we could train workers to reap the labour possibilities that genome editing brings about. Concretely, identify the skills that workers need to learn so that they can carry out the emerging tasks resulting from genome editing and how to teach those skills effectively. Thereby, substituted workers could be reinstated effectively in the disrupted labour market.

Last, I showed that labour implications should be regarded as one of the societal implications of genome editing. Moreover, my findings identify that these implications should not be studied in isolation, as they interact with each other. Therefore, future research could focus on developing a framework that captures the environmental and societal implications of genome editing in a holistic way.

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Appendices

Appendix A: Classification of developed and developing countries

To identify if a country is a developed or a developing country, the country classification list of the United Nations is adopted (United Nations, 2020). The countries are categorized as either ‘developed’ or ‘developing’ economies.

Table A
Developed economies

North America	Europe: European Union	Europe: Other Europe	Major developed economies (G7)
Canada United States **Developed Asia and Pacific** Australia Japan New Zealand	**EU-15** Austria[a] Belgium[a] Denmark Finland[a] France[a] Germany[a] Greece[a] Ireland[a] Italy[a] Luxembourg[a] Netherlands[a] Portugal[a] Spain[a] Sweden United Kingdom[b] **EU-13**[c] Bulgaria Croatia Cyprus[a] Czechia Estonia[a] Hungary Latvia[a] Lithuania[a] Malta[a] Poland Romania Slovakia[a] Slovenia[a]	Iceland Norway Switzerland	Canada France Germany Italy Japan United Kingdom United States

a Member of Euro area.
b At the time of writing, the United Kingdom was a member of the EU and is therefore included in all EU aggregations. The country is scheduled to withdraw from the EU at the end of January 2020.
c Used in reference to the 13 countries that joined the EU since 2004.

Table C
Developing economies by region[a]

Africa	Africa	Asia	Latin America and the Caribbean
North Africa Algeria Egypt Libya Mauritania Morocco Sudan Tunisia **Central Africa** Cameroon Central African Republic Chad Congo Equatorial Guinea Gabon Sao Tome and Prinicipe **East Africa** Burundi Comoros Democratic Republic of the Congo Djibouti Eritrea Ethiopia Kenya Madagascar Rwanda Somalia South Sudan Uganda United Republic of Tanzania	**Southern Africa** Angola Botswana Eswatini Lesotho Malawi Mauritius Mozambique Namibia South Africa Zambia Zimbabwe **West Africa** Benin Burkina Faso Cabo Verde Côte d'Ivoire Gambia Ghana Guinea Guinea-Bissau Liberia Mali Niger Nigeria Senegal Sierra Leone Togo	**East Asia**[b] Brunei Darussalam Cambodia China Democratic People's Republic of Korea Fiji Hong Kong SAR[c] Indonesia Kiribati Lao People's Democratic Republic Malaysia Mongolia Myanmar Papua New Guinea Philippines Republic of Korea Samoa Singapore Solomon Islands Taiwan Province of China Thailand Timor-Leste Vanuatu Viet Nam **South Asia** Afghanistan Bangladesh Bhutan India Iran (Islamic Republic of) Maldives Nepal Pakistan Sri Lanka **Western Asia** Bahrain Iraq Israel Jordan Kuwait Lebanon Oman Qatar Saudi Arabia State of Palestine Syrian Arab Republic Turkey United Arab Emirates Yemen	**Caribbean** Bahamas Barbados Belize Guyana Jamaica Suriname Trinidad and Tobago **Mexico and Central America** Costa Rica Cuba Dominican Republic El Salvador Guatemala Haiti Honduras Mexico Nicaragua Panama **South America** Argentina Bolivia (Plurinational State of) Brazil Chile Colombia Ecuador Paraguay Peru Uruguay Venezuela (Bolivarian Republic of)

a Economies systematically monitored for the World Economic Situation and Prospects report. These analytical groupings differ from the geographical aggregations defined according to M49.
b Throughout the report the term 'East Asia' is used in reference to this set of developing countries, and excludes Japan.
c Special Administrative Region of China.

Appendix B: Interview guide

Interview guide:
1. Shortly describe the purpose of the research
2. Ask permission for recording the interview
3. Always ask for explanation/examples

Question	***Probing question***
How are you engaged with gene editing? *OR* How are you engaged with labour economics in the agricultural sector?	
What is view on genome editing?	
How you think genome editing technologies may affect jobs?	Can you explain that? Can you give another example? Does this only apply to this crop? Or also others?
Are there also jobs that become obsolete?	Does this also affect jobs in the R&D field/ the farming sector (automation/robotization)/ related sectors like the legal, education, transport, or food processing sector?
How does that work?	Does CRISPR lower the demand for some tasks Does CRISPR lower the demand for some skills? Does this work different in genome editing jobs, farming jobs, and jobs in processing/transport/policy?
Where is this happening?	Is this happening in developed or developing countries? Is this happening in rural or urbanized areas?
Are there also jobs that will be newly created?	How will this affect jobs in genome editing/ farming sector/ related sectors like the legal, education, transport, or food processing sector?
How does that work?	Does CRISPR create new tasks? Which skills will be necessary? Does this work different in genome editing jobs, farming jobs, and jobs in education/processing/transport/policy?
Where is this happening?	Is this happening in developed or developing countries? Is this happening rural or urbanized areas?
Are there also jobs that will transform due to gene editing?	How will this affect jobs in genome editing/ farming sector/ related sectors like the legal, education, transport, or food processing sector?
How does that work?	Can CRISPR result in automation? Which tasks will be removed? Which will remain? Which skills become obsolete? Which will remain important?
Where is this happening?	Is this happening in developed or developing countries? Is this happening rural or urbanized areas?
Are there jobs that will remain the same?	How will this affect jobs in genome editing/ farming sector/ related sectors like the legal, education, transport, or food processing sector?
How does that work?	Does CRISPR also increase productivity? Will crops become cheaper?
Where is this happening?	Is this happening in developed or developing countries? Is this happening rural or urbanized areas?
Do you think there will be more or less people employed due to the technologies?	

Outro: Thank you very much for participating. We are now exploring what experts say, but we might be interested in a follow up on what is most important. Is it possible to send you a follow up email later? This will not take a lot of time.

Appendix C: Raw data coding frameworks

	Conditional factors		
Interviewee #	**Regulatory framework**	**Public acceptance**	**Prevailing agricultural system**

Interviewee #	**New jobs**		
	Making sector	**Applying sector**	**Complementary sectors**

Interviewee #	**Transformed jobs**		
	Making sector	**Applying sector**	**Complementary sectors**

Interviewee #	**Substituted jobs**		
	Making sector	**Applying sector**	**Complementary sectors**

Appendix D: Final coding framework

	Conditional factors					
Interviewee #	Regulatory framework	Developed/ developing country	Public acceptance	Developed/ Developing country	Prevailing agricultural system	Developed/ developing country

	New jobs					
	Making sector		Applying sector		Complementary sectors	
Interviewee #	Who and where	Tasks	Who and where	Tasks	Who and where	Tasks

	Transformed jobs					
	Making sector		Applying sector		Complementary sectors	
Interviewee #	Who and where	Tasks	Who and where	Tasks	Who and where	Tasks

	Substituted jobs					
	Making sector		Applying sector		Complementary sectors	
Interviewee #	Who and where	Tasks	Who and where	Tasks	Who and where	Tasks

Appendix E: elaborated table summarizing the jobs that are expected to transform due to genome editing.

Making sector			Applying sector			Complementary sector		
Job description	Tasks	Developed/ Developing country	Job description	Tasks	Developed/ Developing country	Job description	Tasks	Developed/ Developing country
Breeder	(+) Modify the genome of a crop (-) cross and backcross crops	Developed and developing countries	Farmer *Engaging in a more sustainable way of agriculture*	(-) hiring seasonal laborers (developed countries) (-) buying chemicals (both countries) (-) Spraying chemicals (developing countries)	Developed and developing countries	Policy developer	(+) Continuously learn about genome editing (+) Develop a product based regulatory framework	Developed and developing countries
Scientist doing fundamental research	(+) Using genome editing to investigate molecular systems of plants	Developed and developing countries	*Producing herbicide tolerant crops*	(+) Spraying herbicides (-) Weeding (-) Hiring seasonal laborers	Developing countries	Compliance employee	(+) Decide for approval of genome edited crops (+) Check for foreign DNA or off-target effect	Developed and developing countries
Marketeer of genome edited crops	(+) Communicate the advantages in a consumer-oriented way (-) Communicate message associated with industrial agriculture	Developed countries	*Engaging in industrialized precision agriculture*	(+) Analysing data (-) Managing agricultural laborers	Developed countries	Legal consultant	(+) Help breeding organizations to bring their genome edited crop to the market	Developed and developing countries
			Cultivating different crop species	Tasks transform depending on which crops will be produced	Developed and developing countries	Transporters	Tasks change depending on the transportation system. Less distances are covered	Developed countries
			Producing crops with different culture times	Tasks change timewise Hiring practices shift away from seasonal labour	Developed and developing countries	University teachers	(+) Teach genome editing	Developed and developing countries
			Agricultural labourer cultivating different crop species	Tasks transform depending on which crops will be produced	Developed and developing countries			