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Challenges for First-Mile Logistics in Primary Production

LEVITOI Deliverables 1.1 and 1.2

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Contents

Abstract

Primary production, particularly in the agriculture industry, has been and will be affected by climate change. Extreme weather conditions and their effects on the agriculture supply chain and agricultural field soil are highly evident and attract considerable media attention. Although the agriculture supply chain is scrutinized carefully, there is not enough focus on first-mile logistics. The first mile also affects the downstream stages of the supply chain.

These project deliverables aim to enhance the understanding of the challenges of first-mile logistics in poor-bearing soils and vulnerable environments. It seeks to identify and elaborate on different challenges and proposes how agricultural machine and equipment providers might be able to provide solutions.

This research applies both qualitative and quantitative methods. The scientific and gray literature and other sources are scanned to compile the challenges. The fault-tree type of analysis is carried out to categorize and structure the challenges. Next, the information value of the identified challenges is assessed by an evidence-scoring and ranking system. Industrial partners and other field experts are interviewed to ensure the validity of the findings. The quality function deployment (QFD) framework is proposed to link the identified challenges with industrial partners' product features. Lastly, some arguments are provided in order to define the prerequisites of simulation and testing of soil–machine interaction on sensitive soils. Based on the interviews with company representatives, the report also re-examines the first-mile concept, redefines the sequential supply chain, and proposes a hybrid supply chain topology with circular transportation (between pre-harvest and post-harvest phases).

Altogether, 93 challenges are identified and categorized into six different clusters, with subgroups. Through additional expert interviews, it is also found that the majority of the identified challenges are globally acknowledged, except soil compaction. Out of the 93 challenges, merely 24 are acknowledged as important by the interviewed industrial partners, which indicates different priorities of agri-machine business actors.

Based on the QFD analysis, it is suggested that subsequent work packages of the LEVITOI project should enhance laboratory simulation and field-testing efforts to enable making products that cause as little soil compaction as possible in varying weather conditions.

Keywords: First mile, agriculture, forestry, soil compaction, climate change, extreme weather, work machines

Foreword

These deliverables are result of the first-phase research of the LEVITOI project (https://www.oamk.fi/en/partnership/rdi-projects/levitoi-home). The timespan of the project is 2022–2023. The authors thank the LEVITOI partners for their support in this research and gratefully acknowledge the funding of Business Finland (Grant ID 3509/31/2021). A number of experts from Finland and Turkey are also acknowledged for sharing their knowledge.

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1. Introduction

1.1. Objectives and scope of the deliverables

The objectives of the deliverables (D1.1 and D1.2) are to identify, list, and categorize the main challenges faced by first-mile agri-logistics and forestry logistics. The deliverables serve as the first milestone for the LEVITOI project "Leading agri-logistics and machine solutions for changing soil conditions." For pragmatic reasons, the main emphasis is on agri-logistics since the corporate partners of the LEVITOI project are mostly engaged in agri-logistics and associated machine solutions.

The first step in the LEVITOI project (Work Package [WP] 1) is to provide insights to the following research questions:

RQ1.1. What challenges associated with poor-bearing soils and vulnerable environments are encountered by different stakeholders and user segments?

RQ1.2. How can these challenges and problems be structured, that is, how can they be categorized? To what extent are the challenges related to climate change?

RQ1.3. Which of the challenges and problems can prospectively be addressed by machine and vehicle features and technical solutions? What are the implications for sustainable first-mile solutions, and how could these solutions be evaluated and tested?

The first two research questions are adressed in this publicly available deliverable. The third research question is reported as company-specific confidential memoranda.

1.2. Research background

1.2.1. Global food losses in primary production

According to the UN Environment Programme (UNEP), food loss refers to food that gets spilled, spoiled, or otherwise lost, or incurs a reduction of quality and value during its processing stage in the food supply chain (SC) before reaching its final product stage. Food loss typically occurs at the production, post-harvest, processing, and distribution stages in the food SC. Similarly, UN Sustainable Development Goal (SDG) 12.3 states, "*By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses*" (as shown in *Figure 1*). However, millions of tons of food are lost or wasted globally every year at different stages of the SC, from harvesting to household consumption. According to the EU-FUSIONS 2016 report (https://www.eu-fusions.org/), around 88 million tons of food are wasted annually in the European Union (EU) countries, at an estimated cost of approximately €143 billion (Stenmarck *et al.,* 2016). It also highlights that most of the food losses and wastes occur in the post-farming process. According to a report on the state of food and agriculture (Food and Agriculture Organization [FAO], 2019), global food waste accounts for around 13% of the total production, and the food loss in the EU and North America each exceeded 15% in 2016.

A study (Corrado and Sala, 2018) reported that food waste generation along the SC ranged from 194 kg/p/y to 389 kg/p/y at the global level and from 158 kg/p/y to 298 kg/p/y at the EU level. Alexandre (2020) estimated food waste at different parts of the SC, and in primary production and processing, the estimated amounts were 9.1 M tons and 16.9 M tons, respectively. Globally, the food lost between harvest and retail is estimated at around 14% of produced food (FAO, 2019), while the total waste of global food production is estimated at 17% (11% in households, 5% in the food service, and 2% in retail) (Stenmarck *et al*., 2016). Overall, food loss and waste percentages vary in different parts of the SC. Primary production and processing account for 11% and 19% of food waste, respectively, which shows that around one-third of food losses occurs before the food reaches the retail stores (European Environment Agency, 2022).

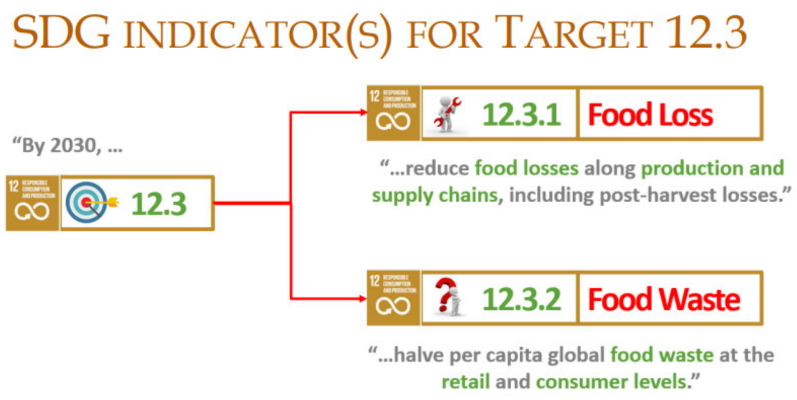


Figure 1. UN Sustainable Development Goals Food Waste Index 12.3
Source: https://food.ec.europa.eu/system/files/2017-04/fw_eu-platform_20170331_fao-activities.pdf

1.2.2. Impacts of climate change on primary production and industries

According to the European Environment Agency (EEA, 2022), climate-related extreme events caused economic losses in the EU-27 member states, at an estimated total of €487 billion between 1980 and 2020 (European Environment Agency, 2022). *Figure 2* shows the total economic loss per capita in EU countries from 1980 to 2020 due to climate change. It can be easily observed that southern, western, and some countries in central Europe were highly affected due to climate change, while northern European countries and southern countries along the Baltic Sea were the least affected by the extreme climate changes and economic losses.

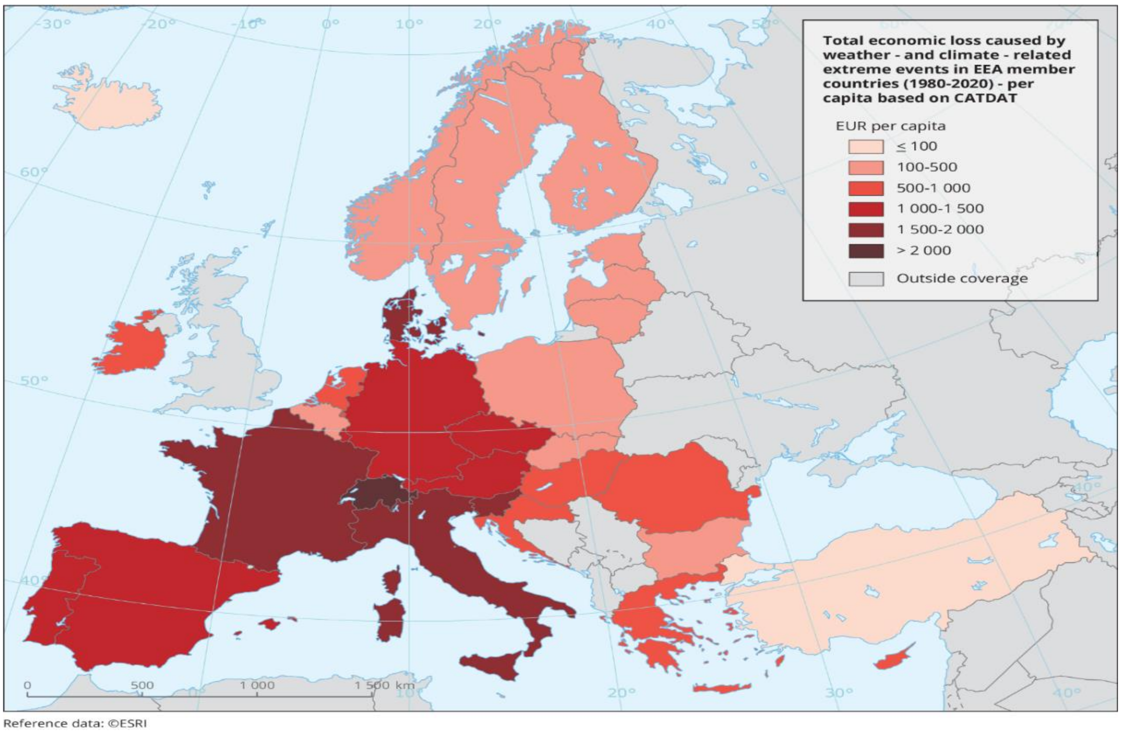


Figure 2. Total economic loss caused by weather- and climate-related extreme events in EEA member countries (1980–2020) per capita, based on CATDAT
Source: https://www.eea.europa.eu/data-and-maps/figures/total-economic-loss-caused-by/

Climate change has both direct and indirect impacts on primary production and agricultural production. *Figure 3* shows how climate change has various effects on agriculture. The physical drivers of climate change include irregular precipitation cycles, extreme weather events, temperature variances, CO2 concentrations, and so on. Some physical drivers directly affect the crop cycle and phenology, disturb water availability in the form of drought and flood, adversely affect the soil moisture and other properties, the efficiency of photosynthesis, and so on. Some of the indirect detrimental impacts might include different pests and diseases due to climate change, invasive species of flora and fauna of agriculture, and so on.

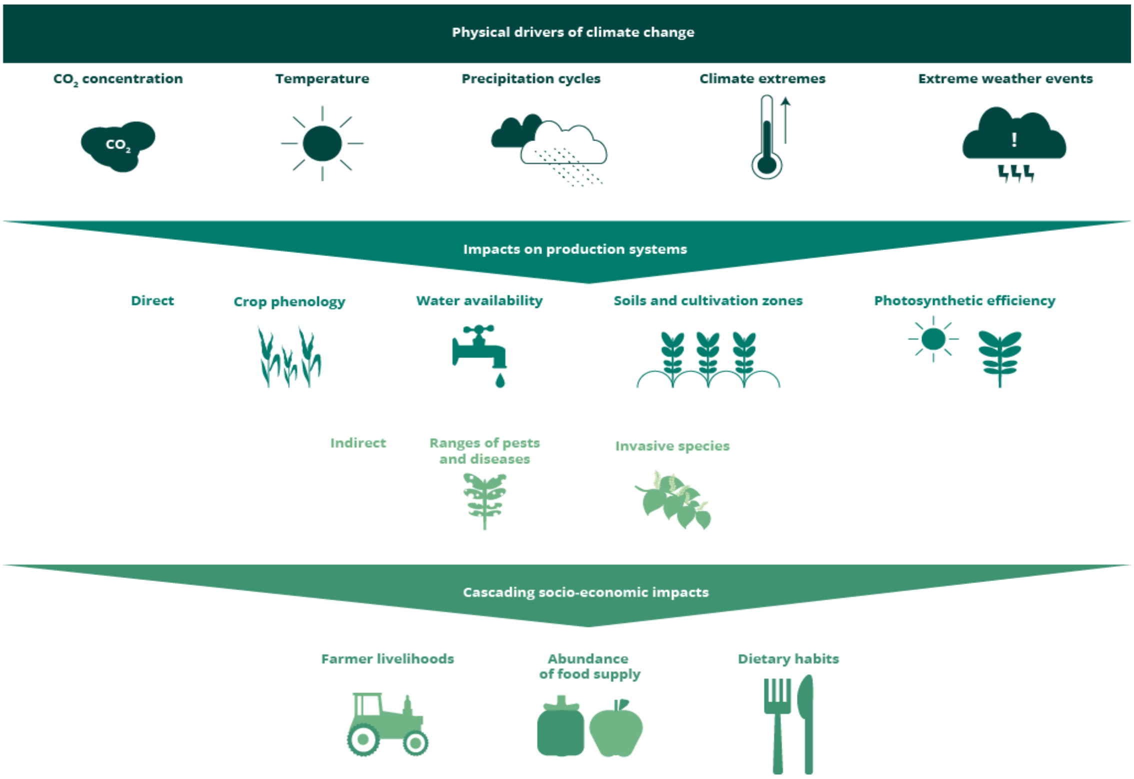


Figure 3. Impacts of climate change on agriculture
Source: EEA Report 2020, Consequences of global climate change and their impacts on Europe, a view on agriculture commodities

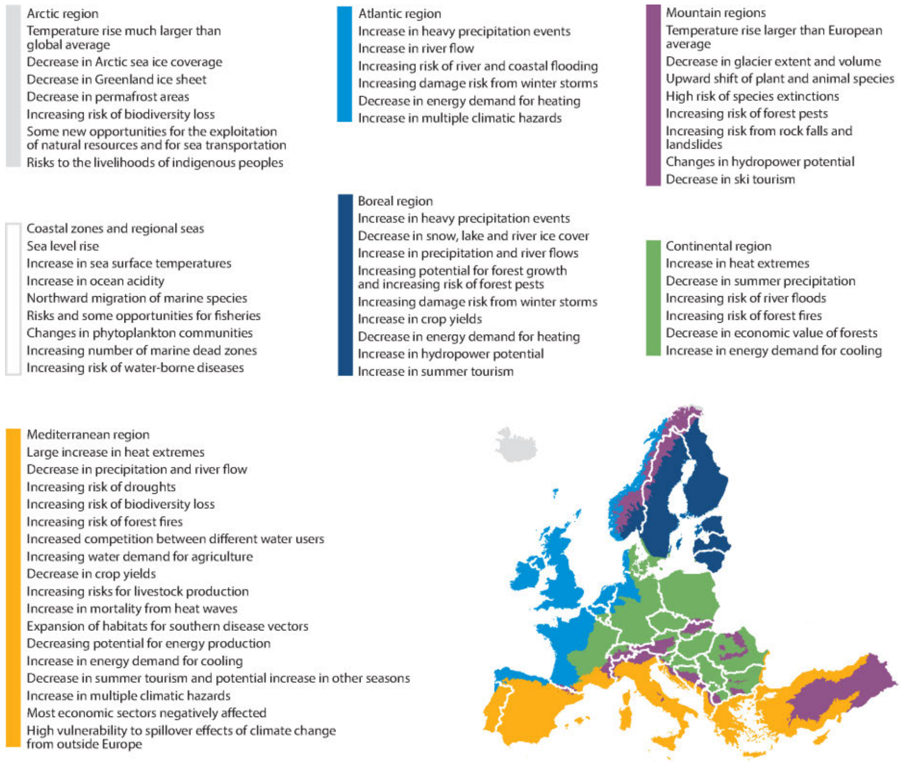


Figure 4. Key observed and projected climate changes and impacts on the main regions in Europe, 2017
Source: EEA https://www.eea.europa.eu/ds_resolveuid/A5ED69B1-636C-413A-9058-7E95A93E5724

According to EEA reports (*Figure 4)* on projected climate change impacts on the EU in 2017, the EU regions are divided into seven regions: the arctic region, the Atlantic region, the mountain region, the coastal zones and regional seas, the boreal region, the continental region, and the Mediterranean region. The countries in the Mediterranean region are at high risk of decreased crop yields, increased biodiversity loss, forest fires, heat waves, among others. In 2022, these countries faced heavy droughts and heatwaves, as well as fires. Similar impacts are projected in continental regions, with the risks of heat waves, floods, forest fires, decreased summer precipitation, and so on. The boreal and the Atlantic regions may experience some positive impacts of climate changes on agriculture, with increased crop yield due to long summer days and fewer snow days in the future.

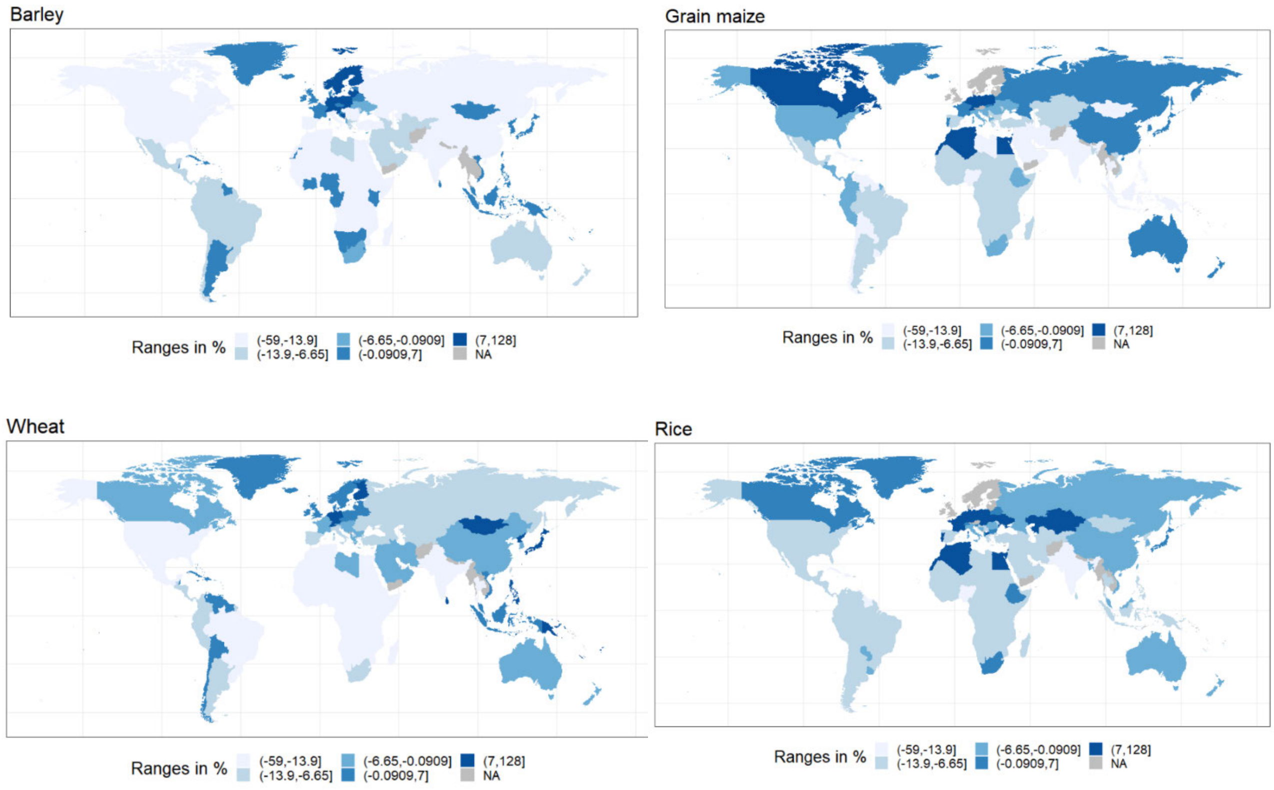


Figure 5. Global climate change ISIMIP-Fast Track median yield changes under the RCP 8.5 and SSP2 scenarios for the selected crops in 2050 relative to the baseline.

Source: JRC Technical Report (2020): https://publications.jrc.ec.europa.eu/repository/bitstream/JRC119632/pesetaiv_task_3_final_report_published.pdf

Figure 5 shows the predicted climate change impacts on different crops worldwide. JCR Technical Report (2020) shows the EU regions as the least affected compared with the Asian and the African regions. It also indicates that Nordic countries might experience some positive impacts on their crop yield, with the reduction in snow days in the future. However, in southern EU countries, climate change might decrease their crop yield, ranging from -6 % to -13%.

Figure 6 shows the annual area of drought impact on vegetation productivity, including grassland, forest and woodland, and cropland of EU countries, from 2000 to 2019. Similarly, *Figure 8* shows the individual countries that are projected to experience the impacts of drought on their croplands, forest areas, grasslands, wetlands, and so on. The forest lands in Finland and Sweden are expected to be highly affected by droughts, while countries such as Greece, Portugal, Cyprus, and Italy are anticipated to have the highest impact on their croplands.

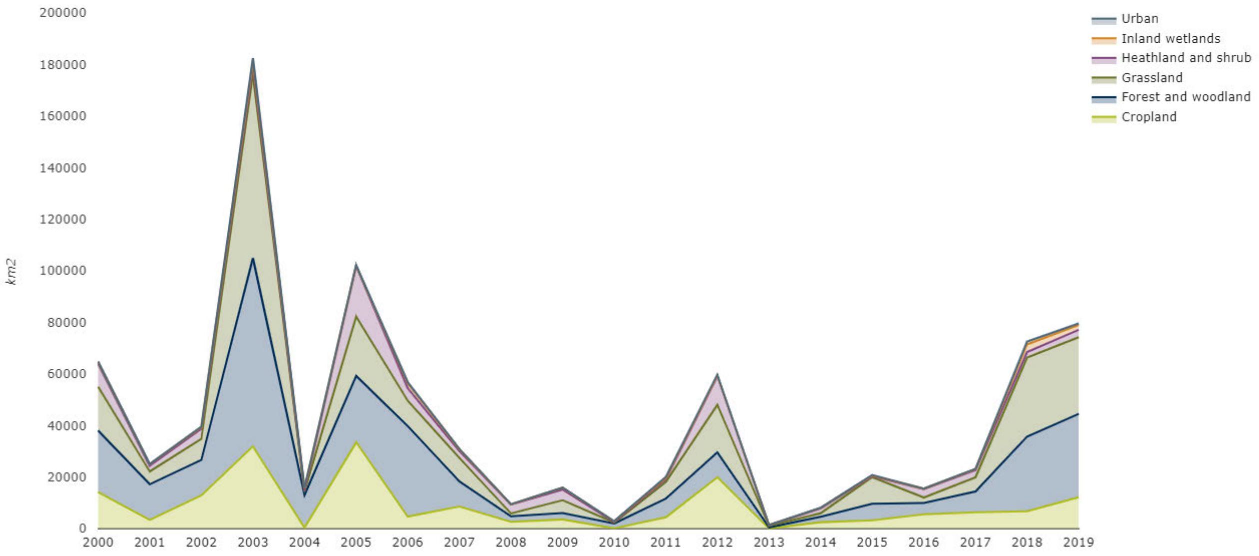


Figure 6. Annual area of drought impact on vegetation productivity (2000–2019)
Source: https://www.eea.europa.eu/ims/drought-impact-on-ecosystems-in-europe

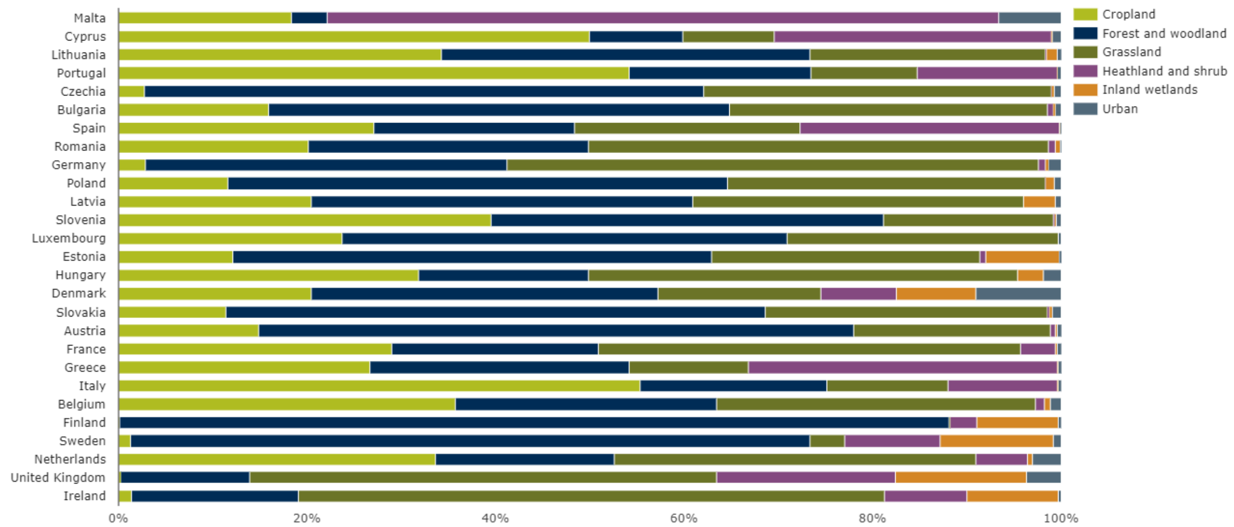


Figure 7. Average annual drought-impacted area by land cover type, as a percentage of the total country area
Source: https://www.eea.europa.eu/ims/drought-impact-on-ecosystems-in-europe

Figure 8 shows the projected changes in different crop types, including barley, grain, maize, rice, wheat, and soybean, in EU countries by 2050. In northern European countries, the overall production is anticipated to experience a minimum negative impact or some positive impact, while southern Europe is projected to suffer from maximum adverse effect on its crop yield. These are due to the projected decrease in snow days in northern Europe and increase in summer temperature and droughts in southern Europe, associated with climate change.

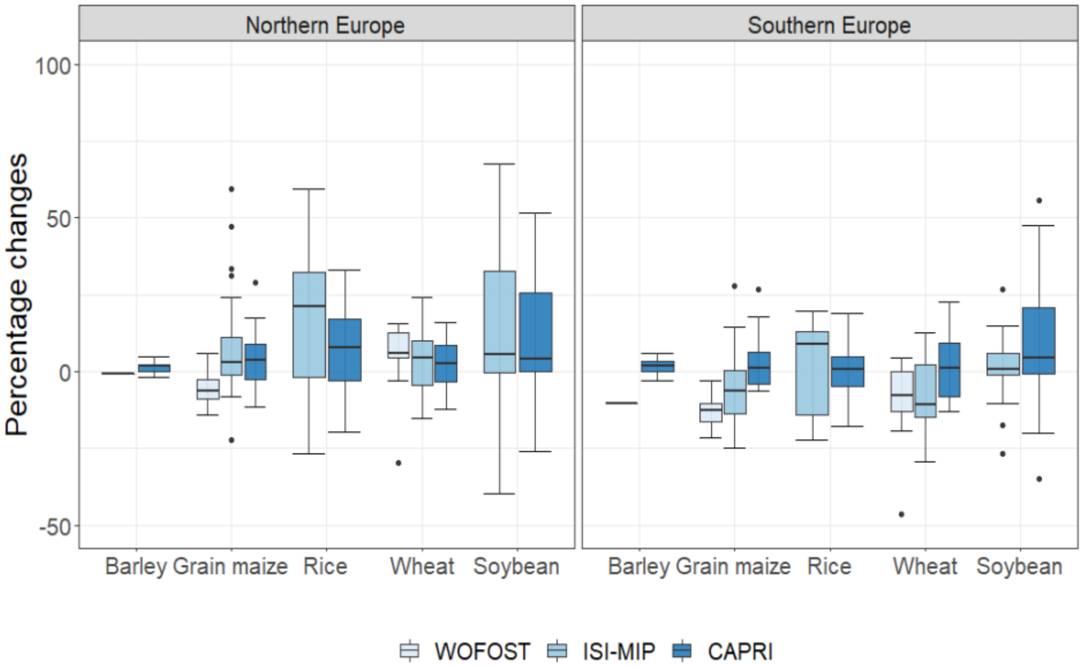


Figure 8. Northern and Southern Europe crop yield changes (exogenous yield shocks (WOFOST/ISI-MIP) and endogenous response (CAPRI)) in 2050 relative to the baseline.
Source: JRC Technical Report: https://publications.jrc.ec.europa.eu/repository/bitstream/JRC119632/pesetaiv_task_3_final_report_published.pdf

According to the report of The Nordic Genetic Resource Center (2019), climate change may also have some positive impacts on Nordic countries due to more favorable conditions for crop production, caused by an increase in annual temperature that favors agricultural production (*Table 1*). These indicators show a potential lengthening of the growing season by 29 days in 2050 in the northern Scandinavian areas but much less in the southern Scandinavian regions. The Nordic region is expected to be less affected by summer drought than southern European regions.

Table 1. Effects of projected climate changes on changes in key agroclimatic indicators in northern European agroecological zones by 2050

Zone	Effective solar radiation (%)	Effective growing days (days)	Date of last frost (days)	Dry days in spring (%)	Dry days in summer (%)
Alpine North (Norway and northern Sweden)	8	29	-10	1	-2
Boreal (Finland, central Sweden, parts of Norway)	8	16	-11	-1	2
Nemoral (south-central Sweden)	8	12	-10	1	11
Atlantic North (western Denmark)	-1	5	-11	-4	21
Continental (eastern Denmark, southern Sweden)	-6	-6	-12	-2	20

Source: Trnka *et al.* (2011).

Source link: http://norden.diva-portal.org/smash/get/diva2:737875/FULLTEXT03.pdf

Crop productivity will increase, and the current main field crops could be cultivated farther north of Europe. Over the next few decades, autumn-sown crops will become more common. However, the predicted increase in the variability of growing conditions will likely increase production risks. In the early growing season, the risk of night frosts will remain, and problems with drought will become more severe, increasing the need for irrigation.

1.3. Role of logistics in primary industries

The agriculture and forestry (AF) industry has been facing numerous challenges in sustainability, digitalization, and food safety, which brings out the crucial need for more efficient agriculture supply chains (ASCs) (Liu *et al.,* 2021; Lezoche *et al.,* 2020). Thus, the ASCs are expected to evolve in order to be more efficient through more productive processes by means of technological and managerial methods and tools (Liu *et al.,* 2021).

The logistics process consists of several harvest, transport, and storage operations (Amiama *et al.,* 2015). For instance, it involves the use of self-propelled forage harvesters, trucks for transport, and machinery for silage packing (Amiama *et al.,* 2015). The process requires coordination, adjusting the number of equipment components on a tight schedule (Amiama *et al.,* 2015).

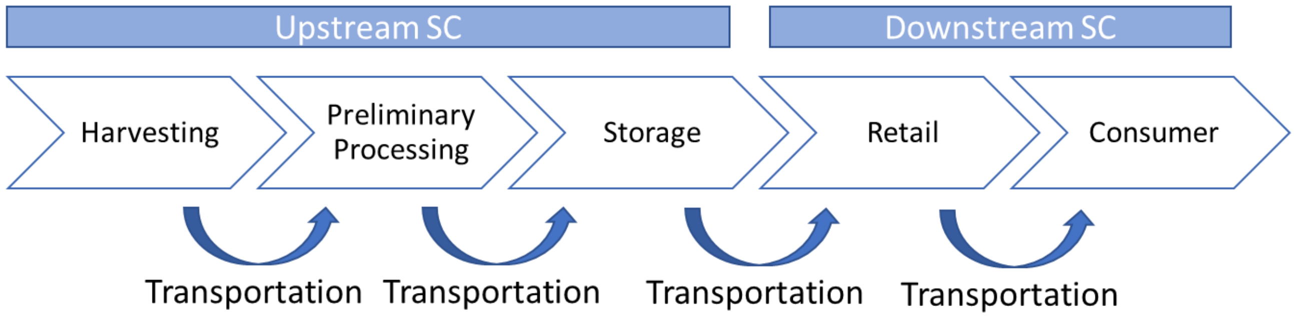


Figure 9. General overview of logistical supply chain

Processing and transportation are estimated to account for around one-third of all energy consumed in agricultural production (Cue´llar and Webber, 2010). More than one-third of global produce is lost due to SC inefficiency (Porter and Reay, 2016). The produce waste occurs at the last stage of the SC, while loss occurs at the first stage of the SC (FAO, 2013). Bourne (1977) divides inefficiencies into two categories, primary and secondary. Primary wastage is transient, meaning that it is partially controllable, such as mechanical damage. Secondary wastage leads to primary wastage and mostly occur due to the structural inadequacies around the SC that needs time, oversight and investment, for instance, legislation, right transport/storage, and cold chain. The cold chain is a method of refrigerating highly perishable commodities, especially for produce that will be transported to far destinations; thus, it can ease the burden of transportation and storage (Porter and Reay, 2016; Soto-Silva *et al.,* 2017).

Small farmers provide nearly three-fourths of the world's food needs, and the agri-forestry business is a significant source of income globally; thus, a more productive SC in primary production has tremendous potential to directly benefit hundreds of millions of poor people in developing countries (Naseer *et al.,* 2019). The bulk volume of fresh produce to be grown and transported is becoming increasingly larger, and the SC is becoming more globally oriented and complicated (Jacxsens *et al.,* 2010). Since the origin of the produce is mostly very far from the consumers' locations, the produce is exposed to the environment (air, soil, water, insects, etc.) until it reaches the consumers, meaning that it has a higher potential to be contaminated (Chai *et al.,* 2007; Gleeson and O'Beirne, 2005; Kärenlampi and Hänninen, 2004).

1.4. The first-mile question

As shown in *Figure 9*, the ASC can be divided into two stages (Naseer *et al.,* 2019). Although we have found that the terms *food waste* and *food loss* have often been used interchangeably in the literature, the FAO (2013) distinguishes food loss from food waste based on the part of the SC where the inefficiency occurs. Waste occurs in the second half of the SC (downstream), while loss occurs in the first half (upstream). Inefficiency occurrence depends on the region and the type of produce; however, it mostly occurs in the extremes of the SC (FAO, 2013). Inefficiency in the downstream SC is beyond the scope of this study and requires solutions regarding human consumption behavior (FAO, 2013). Instead, we focus on the upstream level of the SC, more specifically, on the first-mile logistics. The upstream level of the SC is important for two reasons (Naseer *et al.,* 2019):

(1) It includes farmers who are the main actors of sustainable SC management (SCM).
(2) Activities (positive or negative) at the upstream level severely affect participants at the downstream level (the later stage of the SC).

Agricultural products (mostly perishable) can only be preserved for a very short time; thus, fast and convenient transportation is crucial for loss reduction and efficient trade (Lingjuan *et al.,* 2019). Agricultural products are highly dependent on efficient logistics because of regionality, seasonality, and vulnerability (Lingjuan *et al.,* 2019). The issue of food loss highly depends on the production location (FAO, 2013) since a very high loss occurs at the farmgate (Ahmed *et al.,* 2015). For instance, in Europe and the US, the logistics cost of produce is only about 10% of the total cost, and loss is strictly kept below 5%, while in China, the logistics cost is around 60% of the total cost, and loss in logistics can climb up to 30% (Wang and Zhong, 2008). Thus, coordination is suggested in first-mile operations in order to decrease the cost of first-mile logistics; the coordination applies specifically to the consolidation of harvests, and they act jointly in transporting goods to the next level, such as possible processing or packing (Lingjuan *et al.,* 2019).

Since there is no consistency in the literature about what activities should be included in the scope of first-mile logistics, before the project started, we located first-mile activities, starting with harvesting produce until its storage (*Figure 10*).

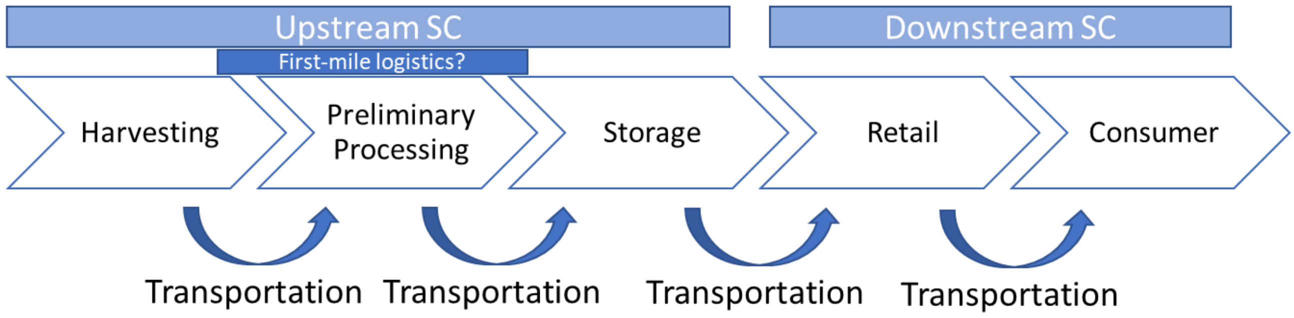


Figure 10. Location of first-mile logistics in supply chain

Some of the definitions of the first mile (logistics) that we have found are listed below:

In the agriculture context, the first mile is defined as *"the primary transport segment between rural farms and markets"* (Bradbury, 2018, p. 2).

"First mile essentially refers to the leg of fulfillment cycle where products are picked up from sellers and are connected to the sortation centers to facilitate the further downstream connections to deliver the product on time to the customers" (Dasgupta *et al.,* 2019, p. 717).

"The first mile of the transport process involves initiation of freight transport using the initial (first in order) means of transport" (Macioszek, 2018, p. 147).

Majluf-Manzur *et al.* (2021, p. 205) use the term *"local logistics"* as well to refer to first-mile logistics.

Bányai (2018, p. 1) describes first-mile logistics as *"the first stage of [the] supply chain"* and notes that together with last-mile logistics, they *"comprise [a] significant part of the total delivery cost and energy consumption."*

The term *"post-harvest logistics"* is also used to cover the same/a similar stage of the SC as first-mile logistics, namely produce handling, transportation, drying, and storage (Mousavi-Avval and Shah, 2020, p. 3).

The definition applied in this deliverable is more extensive in terms of upstream logistics, as on-the-field operations and access to and from seeding and harvesting areas (fields or forestry areas) are included in the first-mile concept. The applied definition may be formulated as follows:

The first-mile problem of the LEVITOI project primarily addresses the in-situ vehicle and machine operations needed to sow and harvest, as well as the transport operations to access the aforementioned areas.

However, in the literature and data source analysis, a broader perspective is taken, thus covering mainly the downstream logistics, but the main focus for subsequent WPs of LEVITOI will be as defined above.

2. Research process and methodology

2.1. Research questions

Climate change has both direct and indirect impacts on AF through irregular precipitation cycles, extreme weather events, temperature variances, CO2 concentrations, and so on. Some physical drivers directly affect the crop cycle and phenology, disturb the water availability in the form of drought and flood, affect the soil moisture/soil compaction and other properties, as well as the efficiency of photosynthesis, and so on. Some of the indirect negative impacts might include different pests and diseases due to climate change, invasive species of flora and fauna, among others. The overall impacts of climate change result in the reduction of crop yield and food supply, thus the concern for food security in the future.

The impacts of climate change will be particularly heavy on poor soils and transport conditions on unpaved roads, such as lower-level access roads (gravel roads) that connect forest and crop/agricultural lands. The first stage of first-mile logistics includes the collection and transfer of the primary products to the first stage of storage (e.g., storage warehouses). Raw materials and products must be picked up and transported farther and farther away, exposing them to the natural environment and to the effects of transporting machines and equipment.

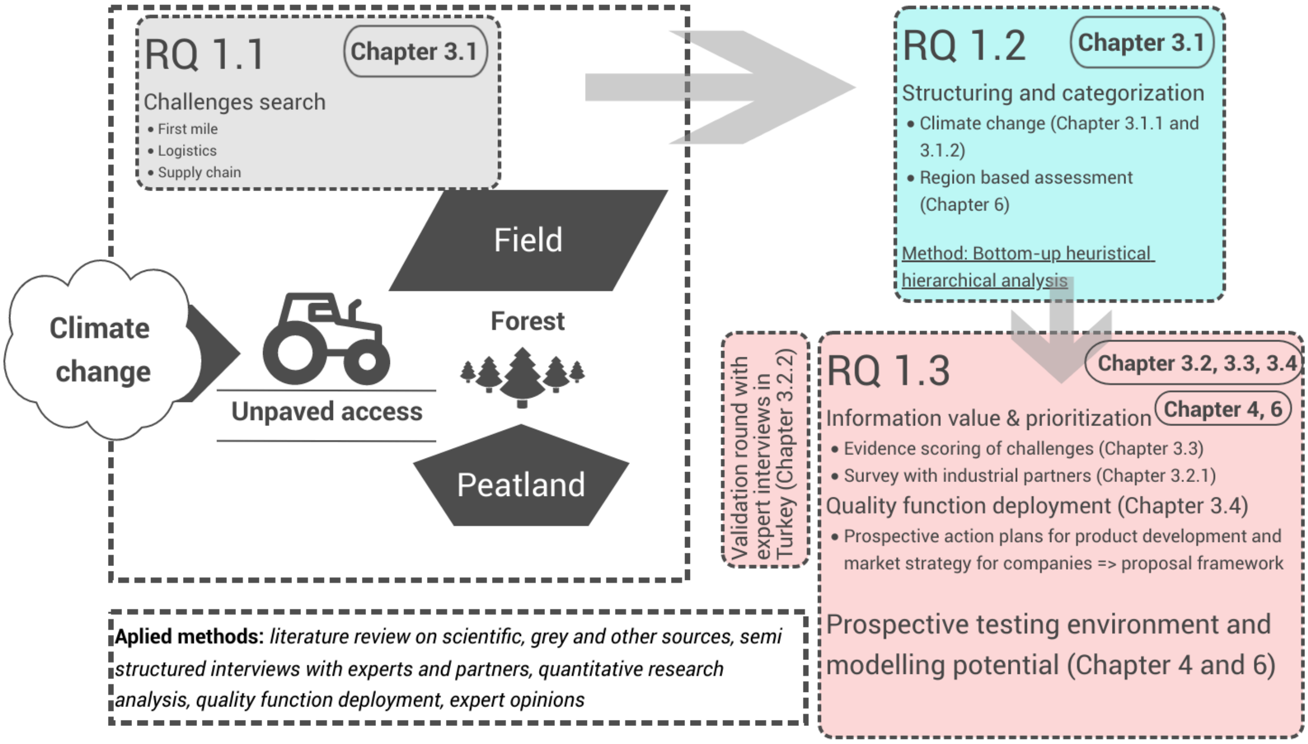


Figure 11. Research Approach

Figure 11 illustrates the conceptual relation between the research questions, acts as a guideline for readers to locate where the research questions are explored in the report, and what methods are applied to explore the research questions.

The ongoing changes impose new requirements on the machinery and equipment used to manage primary production logistics. Different propulsion forces, machine construction, tire solutions, and the right machine systems for the right environments play a key role in the search for solutions. The first-mile problem is insufficiently researched (e.g., compared with the much-studied last-mile problem), and its importance for the efficiency of primary production, as well as the carbon and environmental footprint throughout the value chain, is poorly known.

The LEVITOI project examines the technical solutions provided by machinery and transmission equipment, as required by low-bearing and vulnerable soils, thus producing solutions to the first-mile problem and primary production challenges. In this report, we provide the identified major challenges that may more or less drive the need for new machine and logistics solutions.

2.2. Research process and strategy

The research process, providing the deliverables of D1.1 and D1.2, comprised four main steps (see *Figure 12*):

1. Data and information search (RQ 1.1)
2. Structuring and categorization (RQ 1.2)
3. Information value assessment (RQ 1.2)
4. Solution demand factors (challenges) that can be prospectively translated into technical features of agri-logistics machines and vehicles (RQ1.3).

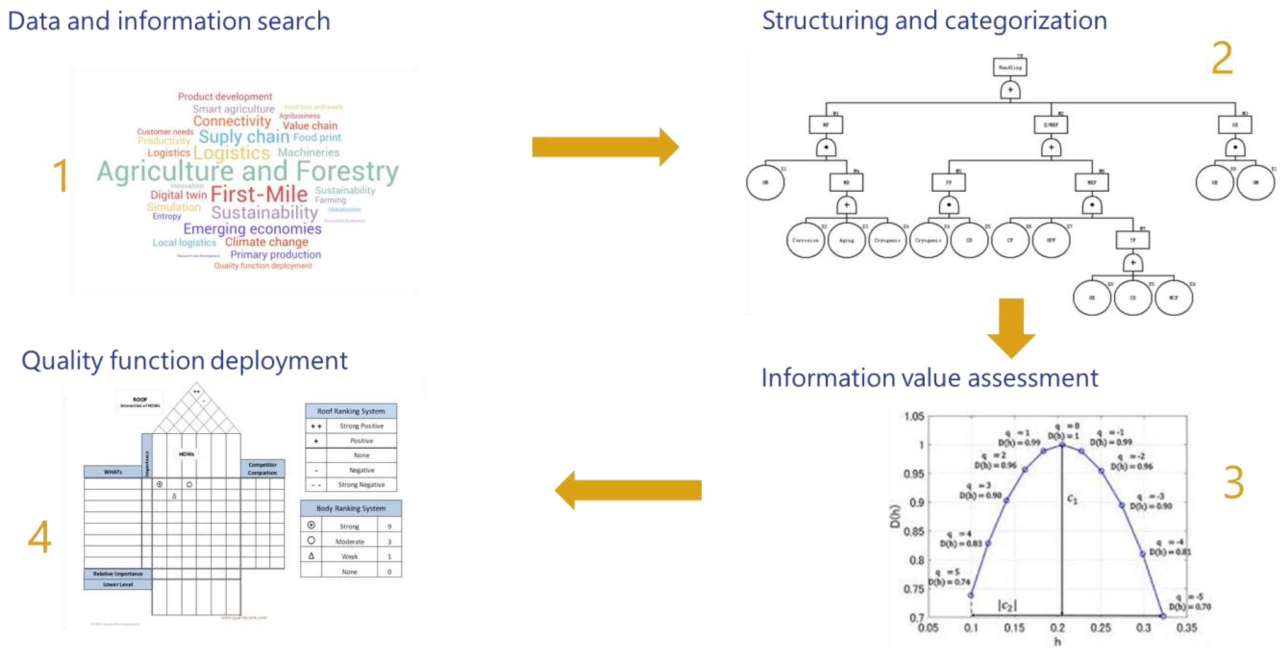


Figure 12. Conceptual illustration of methodology

The research strategy was based on a bottom-up principle, working from the identified individual challenges toward a systemic and hierarchical framework. This made it possible to evaluate the challenges regarded as relevant and having more information value, and finally contributing to building product development tools that would allow companies to assess which challenges could be translated into improved product features and qualities.

2.3. Methodology

LEVITOI WP1 adopted a multi-method approach in answering the research questions. To examine RQ1.1, three types of sources were identified, namely scientific literature, gray literature, and other sources. Scopus has been used as the primary database for articles found from the scientific literature. The following search string was used in line with the scope of the study:

"TITLE (("challenge" OR "problem") AND ("supply chain" OR "logistic") AND ("agri*" OR "forestry")) AND (PUBYEAR > 2012)"

The search string generated a set of scientific literature that included a prominent discussion about the challenges (or problems) of the SC (or logistics) in the spheres of AF over the last ten years. The sources in English were selected only for the research pool. Qualitative research analysis tools, such as NVivo and Mendeley, were utilized during the process for coding. After the elimination, the number of articles was decreased to 27, and all of them were examined carefully.

In the gray literature, we covered multiple sources, including project reports, project deliverables, reports from national and international organizations, case studies, web pages, and news articles. Different search engines, including Google, Yahoo, Bing, Google Scholar, worldcat.org, Library Genesis, and so on, were browsed to gather the reports and other documents. The web search terminologies and keywords, such as "first-mile logistic challenges," "agriculture logistic issues," "agriculture regulation challenges," "infrastructure-related challenges in first-mile agriculture logistics," "climate change impact on agriculture," "post-harvesting challenges," "agriculture supply chain issues," "soil compaction impact on agriculture," among others, were used to find the challenges from the gray literature.

Semi-structured interviews were conducted with the industrial partners of the LEVITOI project, mostly exporters; they were visited in their offices, and data were also collected from those interviews in April 2022. The challenges that they mentioned were not found in our search for information from the scientific and gray literature scanned from other sources. Other sources included selected project reports and materials, website information, blogs, professional magazines, and typically, materials that had not been formally peer reviewed and could not be necessarily considered official data or information. However, in some places, the division among scientific literature, gray literature, and other sources was not entirely clear, but this ambiguity was deemed non-critical.

As a result of our information search, we had an enormous amount of text that sources discussed directly or indirectly about challenges in the first-mile logistics of the agriculture industry. There were limited data about forestry. All texts were coded in the qualitative data analysis tool NVivo. At least two researchers were involved in this process; thus, numerous meetings were held to align the coding and the process. At the initial stages, there were more than 30 groups of challenges, and almost 200 challenges were identified. The challenges that were similar in the context of agri-logistics were combined and grouped. After brainstorming sessions and discussions with industrial and research partners, a hierarchical tree was created, sometimes with many branches, at other times, with none at all. For instance, the category of SCM and logistics 3 level had more subdivisions, while the category of regulations had none. After all of these, the challenges identified from the scientific and gray literature and other sources were consolidated and coded together.

The outcome of our information search is presented with subcategories under *Chapter 3*, *Section 3.1. Data and information search and structuring and categorization of the data*. The categorization is often described in the categories, in addition to the presentation of the whole tree diagram in *Section 3.1.4. Hierarchical structure of challenges*.

Regarding the information value assessment, the process started with evaluating the evidence level of the references in our research pool. The idea of ranking references based on their evidence level has been applied prominently in medical sciences for a long time (Stichler, 2010). A six-level ranking was applied in our research pool, and each reference was ranked, following the guidance of Stichler's (2010) work. Level-6 references were the least evident, while Level-1 references were the most evident in this ranking. Level 1 basically consists of a meta-analysis or a systematic review of evident research sources, while Level-6 sources are mostly stakeholder opinions and might be subjective. Based on the number of references each challenge was extracted, and evidence levels of those references, a mathematical equation was developed to give an overall dominance score for each challenge. The main goal was to differentiate the challenges based on their dominance in the literature. The median dominance score and the standard deviation were calculated, and the challenges were ranked based on their dominance levels: high dominance, dominance, medium dominance, and low dominance. More detailed information about the method of information value assessment and the results can be found in *Chapter 3, Section 3.3*.

Quality function deployment (QFD) is another method applied in this study. Developed in Japan in the 1960s, it is a flexible and comprehensive decision-making tool for product management, centering on customer requirements. In our case, the customer requirements can be understood as the first-mile challenges of the agriculture industry, found in recent literature. The house of quality matrix is a sheet that is used to apply QFD and has six major components: customer requirements, technical specifications, planning matrix, interrelationship matrix, technical correlation matrix, and technical priorities. The identified challenges were presented to the industrial partners, and their opinions were solicited with an online survey tool. Two out of the four industrial partners responded to this survey; thus, the house of quality was created for each of them. The main reason was that the challenges were constrained by those ranked as *important* or *crucial* by individual industrial partners; moreover, the tool is company specific. The applied analysis example is presented in *Chapter 3, Section 3.4*. The researchers have the free template of the analysis tool, which is ready to be shared with industrial partners and can be updated with company-specific details, based on their needs.

3. Results

3.1. Data and information search and structuring and categorization of the data

3.1.1. Scientific literature

The nature of the identified challenges denoted interrelations among the clusters; however, we always found enough evidence for grouping the challenges under certain themes. In total, 92 different challenges were extracted from 27 distinct scientific publications. The included studies in the research pool either directly or indirectly discussed the challenges around first-mile logistics in AF. The research pool solely consisted of publications written in English; thus, resources in other languages were excluded. This has implications for the coverage of information gain. However, with respect to scientific sources, the implications are assumed to be minimal.

Infrastructure-related challenges

The issues related to infrastructure were divided into two subcategories: physical and digital infrastructure. Despoudi *et al.* (2021) found that the lack of technology adoption in a general context was a problem in the Greek agriculture sector. Technology adoption in logistics was found to be at an insufficient strategic level (Xiao-yuan and Wei-hua, 2013). Hardware facilities were mentioned as insufficient, and adoption of new technological developments such as Internet of Things (IoT) and blockchain were defended as challenges in digital infrastructure in the industry (Tang *et al.,* 2013; Bannor and Kyire, 2021; Srivastava and Dashora, 2022), which are promising methods to enable tracking the on-site and from/to site logistics. However, according to Mirabelli and Solina (2020), the current maturity level of technology is not enough for tracking the supply chain, excluding blockchain technology.

Evidently, the lack of infrastructure in the ASC was defended as a major issue, particularly in emerging markets, where food supply proportionally takes a huge share in their domestic economies

(Raut *et al.,* 2019). According to Gardas *et al.* (2019), the seasonality of the agriculture industry makes the process tedious and discourages investments in infrastructure projects, in addition to the typical long gestation of infrastructure projects (Raut *et al.,* 2019). It should also be mentioned that the lack of infrastructure is particularly prevalent in transportation, especially in rural areas (Naseer *et al.,* 2019; Xiao-yuan and Wei-hua, 2013).

Two studies found storage capacity and quality to be insufficient (Naseer *et al.*, 2019; Xiao-yuan and Wei-hua, 2013). In this regard, as the cold chain is a method of refrigerating highly perishable commodities, Tang *et al.* (2013) presented inefficiency in refrigerated transportation as an issue. Tang *et al.* (2013) mentioned other challenges related to the cold chain, such as the lack of overall planning and integration of the upstream and the downstream of cold chain logistics, the limited volume of the cold chain market, and the small portion of third-party cold chain logistics enterprises. Challenges regarding cold chain logistics have subsequently been presented and argued by Han *et al.* (2021).

At the downstream stage of the SC market, infrastructure was argued as lacking as well (Gardas *et al.,* 2018). The complex road network and hazardous transportation routing act as catalysts of infrastructure-related issues (Tang *et al.,* 2013; Kresnanto *et al.,* 2021). Road infrastructure and packaging facilities are last but not the least of the issues in the infrastructure cluster (Naseer *et al.,* 2019).

Regulation-related challenges

The cluster of regulatory issues is the smallest group; however, the sources do not point out less important challenges. The lack of understanding of constantly changing regulations was presented as a crucial challenge (Despoudi, 2021). Producers take buyers as their regulation consultants. In other words, they follow what buyers request from them about produce and production methods. However, this poses several issues; for example, buyers might change in the process of production, and the information source is not very reliable inherently. The interviewees in Despoudi's (2021) study also stated that they could not afford all the quality requirements from buyers. The difficult and complicated licensing process, often not very transparent, was found to eliminate small farmers or entrepreneurs in agri-business; this issue was raised as a fundamental challenge at the farmgate (Gardas *et al.,* 2019).

SCM and logistics-related challenges

The cluster of SCM and logistics-related challenges has two large subgroups: SCM and logistics. Issues related to collaboration and coordination of SC partners and information management can be grouped under SCM. Global trade inevitably increased the distance between production and the market, and this relatively new phenomenon brought other issues to solve in the industry and increased the complexity in SCM, with numerous nodes of produce to be delivered (Lingjuan *et al.,* 2018), and led to heavy produce loss in the SC (Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013). At the organizational level, we found references about inadequate technical support, lack of trust, and unavailability of needed information among stakeholders (Naseer *et al.,* 2019; Awan *et al.,* 2021). The existence of intermediaries throughout the SC seems to cause some issues, such as exploitation and the lack of competition among them, which limit producers' decisions (Naseer *et al.,* 2019). As of coordination and leadership, the vast majority of the issues is related to the lack of integrated processes (Lingjuan *et al.,* 2018; Patidar *et al.,* 2018), the lack of coordination among stakeholders in different directions (Majluf-Manzur *et al.,* 2021; Soto-Silva *et al.,* 2017; Despoudi, 2020; Awan *et al.,* 2021; Naseer *et al.,* 2019; Gardas *et al.,* 2018; Wen *et al.,* 2017; Patidar and Agrawal, 2020), and barriers related to information exchange (Naseer *et al.,* 2019; Lingjuan *et al.,* 2018; Yang *et al.,* 2014; Bannor and Kyire 2021).

Continuing with processes that are not sufficiently integrated—because of the lack of either capability or endeavor (Lingjuan *et al.,* 2018; Patidar *et al.,* 2018)—pressures information flow, which is already decentralized (Lingjuan *et al.,* 2018), and creates barriers to swift exchange (Lingjuan *et al.,* 2018; Yang *et al.,* 2014). In the study of Naseer *et al.* (2019), the interviewees also found it challenging to access the latest information about production. Tracking eases coordination and integration of processes; thus, transparency is required for information exchange and coordination, which was mentioned as lacking (Bannor and Kyire, 2021; Awan *et al.,* 2021).

The lack of coordination efforts in many directions was found to be a significant problem in some studies: the lack of coordination efforts among farmers (Naseer *et al.,* 2019), the lack of coordination efforts throughout the SC (Wen *et al.,* 2017), and at the market level (Gardas *et al.,* 2018). As mentioned earlier, integration of these stages is also an issue (Patidar *et al.,* 2018). We observe a huge coordination and integration issue in varied directions within and between the stages of the ASC; the issue is related to not only the integration of stakeholders but also the processes.

Along with fragmented lands and a lengthy SC, the numbers of nodes of produce are too large in many parts of the world, which puts pressure on the optimization of (first-mile) logistics (Yang *et al.,* 2014; Lingjuan *et al.,* 2018; Patidar and Agrawal, 2020; Gardas *et al.,* 2019; Raut *et al.,* 2019). The industry suffers from traditional packaging, as well as the lack of transportation equipment and infrastructure, cold chain, and packaging infrastructure (Porter and Reay, 2016; Soto-Silva *et al.,* 2017; Naseer *et al.,* 2019; Xiao-yuan and Wei-hua, 2013; Han *et al.,* 2021). Thus, storage and transportation must go hand in hand to optimize logistics at various levels (including coordinated cold chain logistics with the help of technology), decrease produce loss, and improve productivity (Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013; Majluf-Manzur *et al.,* 202; Xiao-yuan and Wei-hua, 2013).

Economics, business and finance-related challenges

The challenges related to economics, business, and finance are grouped into six distinct but interrelated subclusters: transport economics, business models, investment, efficiency and productivity, market-related issues, and quality.

Starting with cost-related issues, along with the increase in the cost of fuel, often caused by turbulent international politics, has direct effects on agri-transportation and thus on the SC cost (Gardas *et al.,* 2018). Along with fuel cost, improving SC productivity comes at a cost, and this creates financial issues for not only farmers but nearly all parties throughout the SC (Lingjuan *et al.,* 2018; Raut *et al.,* 2019; Gardas *et al.,* 2018).

Traditional management is still dominant in the agriculture industry, not only at the farmgate but throughout the SC (Sadati *et al.,* 2019). Farming practices, such as irrigation, are predominantly applied in an outdated way (Naseer *et al.,* 2019), which is both unsustainable and harmful to producers. Management practices are based on individuals' perspectives and experiences rather than focusing on how to improve the technical process and the business with the support of professionals (Sadati *et al.,* 2019; Naseer *et al.,* 2019; Patidar *et al.,* 2018; Despoudi *et al.,* 2021; Tang *et al.,* 2013). With this said, the lack of coordination among stakeholders, particularly at the farmgate, affects business key performance indicators immensely (Naseer *et al.,* 2019; Despoudi *et al.,* 2021; Sadati *et al.,* 2019). Small-sized farm fields force small-sized production and lead to less usage of machinery and of smart/automated processes and fields. SC processes become unproductive and inefficient, which creates another reason for produce loss and in this sense, decreases profitability in the agriculture sector (Lingjuan *et al.,* 2018; Naseer *et al.,* 2019; Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013). It should be noted as well that Tang *et al.* (2013) focused on the efficiency of refrigerated transport and mentioned that it would require specific attention. Lastly, Xiao-Yuan and Wei-Hua (2013) notified the industry partners about the low level of processing of produce, which evidently eased logistics and SC efforts.

High input costs—and costs in general—in SC make access to credit crucial (Naseer *et al.,* 2019; Raut *et al.,* 2019; Lingjuan *et al.,* 2018). In the study of Naseer *et al.* (2019), the interviewees stressed the importance of quality incentives for grading by size and packaging. Moreover, the lack of marketing investment was presented as an issue (Naseer *et al.,* 2019). Regarding the relation between the farmgate and the market stage, the lack of market price information, rigging in fruit and vegetable market price settlements, the distance from fruit and vegetable markets (Naseer *et al.,* 2019), the lack of understanding of changing market requirements (Despoudi *et al.,* 2021), the large number of marketing channels, the limited agricultural market infrastructure, the low price realization of agricultural produce by farmers, restricted access to agricultural produce markets, and the cost of marketing (Gardas *et al.,* 2018) are other identified challenges. In addition to uncertainties on the production side, for instance, harvest yield or seeding performance, caused by mostly weather and increased with global warming (Onggo *et al.,* 2019), the market is also uncertain and creates huge challenges in the sector, especially at the farmgate, considering their distance to the other side of the SC (Sadati *et al.,* 2021; Chaerani *et al.,* 2022; Violi *et al.,* 2019). Last but not least, integration is needed at every level of the SC, including the market phase (Gardas *et al.,* 2018).

As for quality-related challenges, the lack of awareness about quality is a fundamental issue (Naseer *et al.,* 2019.) Incentives are needed to direct the focus of producers to the concept of quality, particularly the quality of produce, packaging, and matching product features with market expectations (Naseer *et al.,* 2019). Supportive chemicals such as fertilizers and pesticides are growing in importance since climate change aggravates farming processes; thus, their quality is becoming more crucial (Naseer *et al.,* 2019; Despoudi, 2021).

Natural environment and phenomena-related challenges

Some of the issues arising under nature-related challenges are not directly related to global warming/climate change, but others are. However, according to the analyzed studies, climate change acts as a catalyst of almost all other challenges, either related or unrelated to the environment.

As discussed earlier, the agriculture sector is one of the main subsidiaries of primary production business. Thus, it is tightly connected to nature (Cagliano *et al.,* 2016) and affected by seasonality (Raut *et al.,* 2019), climate change (Naseer *et al.,* 2019; Despoudi, 2021), and uncertainty in harvest (Onggo *et al.,* 2019) or other stages of production. Climate change triggers extreme weather (Naseer *et al.,* 2019; Gardas *et al.,* 2019; Despoudi *et al.,* 2021), and with the new climatic conditions, fresh water is becoming increasingly scarce, and its accessibility is becoming a larger issue (Naseer *et al.,* 2019; Gardas *et al.,* 2019). Soil fertility is deteriorating with climate change, and the quality of fertilizer is becoming insufficient (Naseer *et al.,* 2019). Perishability of produce is a natural issue, and with globalization, it is becoming a greater issue (Naseer *et al.,* 2019; Violi *et al.,* 2020), yet the cold chain is presented as a prospective solution, and its challenges are under the lens of experts and researchers (Tang *et al.,* 2013; Han *et al.,* 2021). Once more, with climate change and globalization in agriculture, pest and disease attacks on produce are increasing and putting pressure on improving the quality of pesticide (Naseer *et al.,* 2019; Despoudi, 2021).

Skill set and workforce-related challenges

Some issues related to the labor force and technical professionals have been spotted in the scientific literature and are noteworthy. Despoudi *et al.* (2021) mentioned the *lack of farm-related skills and the need for modern agricultural practices*, which can be connected by other identified challenges, such as the dominance of *traditional management* in the agriculture industry. The shortage of comprehensive professionals was mentioned (Tang *et al.,* 2013), and labor performance was reported as insufficient (Naseer *et al.,* 2019).

Summary

Table 2. Summary of findings from scientific literature review

Clusters	References	Main Issues
1. Infrastructure		
1.1. Physical		Complex road network, inadequate road infrastructure, lack of cold chain facilities, insufficient storage infrastructure, poor packaging practices
1.1.1. Road Network	Tang *et al.,* 2013; Naseer *et al.,* 2019; Kresnanto *et al.,* 2021	
1.1.2. Storage and Warehouses	Gardas *et al.,* 2018; Porter and Reay, 2016; Soto-Silva *et al.,* 2017; Raut *et al.,* 2019; Naseer *et al.,* 2019; Xiao-yuan and Wei-hua, 2013; Tang *et al.,* 2013	
1.2. Digital		Lack of blockchain and IoT adoption, lack of logistic technology and hardware facilities
1.2.1. Communication Network	Bannor and Kyire, 2021; Srivastava and Dashora, 2022	
1.2.2. IoT	Yadav *et al.,* 2020; Xiao-yuan and Wei-hua, 2013	
1.2.3. Others	Mirabelli and Solina, 2020; Bannor and Kyire, 2021; Srivastava and Dashora, 2022; Despoudi, 2021; Tang *et al.,* 2013	
2. Regulatory Issues	Despoudi, 2021; Gardas *et al.,* 2019	Lack of understanding of the changing regulations, licensing hurdles
3. SCM and Logistics		
3.1. Supply Chain		InadequateInformation flow, lack stakeholder integration, unnecessary intermediaries, lack of coordination, too many nodes of produce, waste in supply chain
3.1.1. Collaboration	Naseer *et al.,* 2019; Awan *et al.,* 2021; Gardas *et al.,* 2018	
3.1.2. Information Management	Bannor and Kyire, 2021; Awan *et al.,* 2021; Naseer *et al.,* 2019; Lingjuan *et al.,* 2018; Yang *et al.,* 2014	
3.1.3. Coordination and Leadership Issues	Naseer *et al.,* 2019; Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013; Majluf-Manzur *et al.,* 2021; Soto-Silva *et al.,* 2017; Despoudi, 2021; Patidar *et al.,* 2018; Wen *et al.,* 2017; Lingjuan *et al.,* 2018	
3.2. Logistics		Lack of coordination, lack of cold chain facilities, poor transportation infrastructure, excessive circulation links, lengthy of logistic chain, produce loss, poor packaging practices, low level of logistics technology adoption
3.2.1. Transport Issues	Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013; Majluf-Manzur *et al.,* 2021; Porter and Reay, 2016; Soto-Silva *et al.,* 2017; Han *et al.,* 2021; Naseer *et al.,* 2019; Xiao-yuan and Wei-hua, 2013; Yang *et al.,* 2014; Lingjuan *et al.,* 2018	
3.2.2. Storage and Warehouses		
i) Packaging and material handling	Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013; Naseer *et al.,* 2019	
ii) Storage facilities	Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013; Porter and Reay, 2016; Soto-Silva *et al.,* 2017; Han *et al.,* 2021	
4. Economics; Business and Finance		
4.1. Transport Economics		Cost throughout supply chain, increase in cost of fuel
4.1.1. Transport Costs		
4.1.2. Other Cost Issues	Raut *et al.,* 2019; Lingjuan *et al.,* 2018; Gardas *et al.,* 2018	
4.2. Business Models		Lack of planning, traditional management, lack of coordination
4.2.1. Business Case Issues	Naseer *et al.,* 2019; Patidar *et al.,* 2018; Tang *et al.,* 2013	
4.2.2. Business Ecosystem Issues	Sadati *et al.,* 2019; Majluf-Manzur *et al.,* 2021; Naseer *et al.,* 2019	
4.3. Investment	Naseer *et al.,* 2019	Difficulty in access to credit, lack of incentives and marketing investment, high input cost
4.4. Efficiency and Productivity	Lingjuan *et al.,* 2018; Naseer *et al.,* 2019; Gardas *et al.,* 2018; Patidar and Agrawal, 2020; Raut *et al.,* 2019; Tang *et al.,* 2013; Xiao-Yuan and Wei-Hua, 2013	Fragmented land, produce loss, low level of processing, outdated irrigation, low efficiency of cold chain
4.5. Market Issues	Naseer *et al.,* 2021; Gardas *et al.,* 2018; Despoudi, 2021; Sadati *et al.,* 2021; Chaerani *et al.,* 2022; Violi *et al.,* 2019; Tang *et al.,* 2013; Onggo *et al.,* 2019	High cost of marketing, lack of understanding of changing market, lack of awareness onprice settlement, lack of integration, uncertainty in harvest, large distance of production from market
4.6. Quality	Gardas *et al.,* 2018; Naseer *et al.,* 2019; Despoudi, 2021	Low produce quality, quality ignorance, lack of quality in fertilizers and pesticide, lack of incentives for packaging
5. Natural Environment and Phenomena		
5.1. Extreme Weather	Naseer *et al.,* 2019; Despoudi, 2021; Gardas *et al.,* 2019; Cagliano *et al.,* 2016	Negative impacts of climate change, tight connection to nature
5.2. Others	Gardas *et al.,* 2019; Naseer *et al.,* 2019; Despoudi, 2021; Violi *et al.,* 2020; Raut *et al.,* 2019; Cagliano *et al.,* 2016; Onggo *et al.,* 2019	Disease and pest attacks, perishable products, shortage of fresh water, deteriorating soil fertility
6. Skill Set and Workforce	Despoudi, 2021; Naseer *et al.,* 2019; Tang *et al.,* 2013; Majluf-Manzur *et al.,* 2021	Lack of farm-related skills for modern agriculture, issues related to labor force, lack of comprehensive professionals

3.1.2. Gray literature

The grey literature covers the challenges related to first-mile logistics in agriculture, which include both harvesting and post-harvesting processes. Overall, the challenges are categorized into six different areas:

1. Infrastructure-related challenges
2. Regulation-related challenges
3. SCM and logistics-related challenges
4. Economics, business and finance-related challenges
5. Natural environment and phenomena-related challenges
6. Skill set and workforce

These six categories are further divided into sub-categories, which are discussed here in detail. In total, around 60 challenges are identified from the gray literature, which covers the six areas. The sources of those 60 challenges include annual reports, case studies, website articles, chapters of books, thesis works, working papers, and so on. The reports comprise both international organizations' (UN, EU, World Bank, Asian Development Bank, and African Development Bank) annual reports and companies' project reports. In total, 40 references cover the 60 challenges identified from the gray literature. The majority of the challenges overlap with those obtained from the scientific literature; however, some of the challenges are unique to the gray literature.

Infrastructure-related challenges

The challenges related to infrastructure are categorized into physical and digital infrastructure. Physical infrastructure includes challenges related to road networks, storage, warehouses, and so on. Some of these challenges are inadequate post-harvest management infrastructure, poor road network, as well as the lack of rural accessibility, access to farmland, cold chain facilities, and so on. Digital infrastructure-related challenges involve advanced technologies, IoT, communication networks, among others. The list of challenges includes high telecommunication costs, inefficient tracking system, the lack of advanced technologies and access to machinery and equipment, and so on. The challenges related to infrastructure are discussed in the following paragraphs.

Different reports and studies (US Department of State, 2013; Banjo *et al.,* 2012; Ludwig *et al.,* 2016; Iimi *et al.,* 2015; EU, 2017) have shown that farmers in developing countries mainly struggle and those in developed nations partly struggle due to poor road availability and quality, which limit their access to domestic, regional, and international markets. According to the Annual Report on the

Results and Impact of the International Fund for Agricultural Development (IFAD) Operations, poor roads result in increased transport costs and a higher likelihood of damage to crops during transportation (IFAD, 2009). This constraint is especially prevalent in rural areas, where farmers lack access to competitive markets in which they could buy inputs and sell outputs.

Poor physical infrastructure—especially rural and lower-level (private) roads—constitutes another significant challenge to agriculture in developing countries. One-half of the rural population of South Asia lives within an hour's trip to a market, whereas nearly 50% of African farmers still live 5 hours or more from a market (African Development Bank, 2010). In addition to the few rural roads, the transport costs in developing nations are among the highest in the world, reaching as much as 77% of the value of exports in the case of African countries (African Development Bank, 2010). Moreover, poor infrastructure and the lack of information leave farmers effectively isolated from regional or international markets.

The lack of cold chain facilities in the first mile is another prominent issue. Besides the lack of on-farm post-harvesting facilities, the density of the refrigerated warehouses in the first mile remains low (US Department of State, 2013; Xuezhen *et al.,* 2020; Tani Hub, 2020). This makes it very difficult to find nearby warehouses to store products, which expands the time lag between product harvesting and cold storage. This becomes more critical in the case of fruits and vegetables because they are vulnerable produce requiring quick transport to cold storage to preserve the product quality as much as possible. The long distances between farms and cold warehouses increase the lead time between harvesting and cold storage, which can decrease the product quality significantly. Aside from the low density of cold storage, the warehouses' inadequacy in both capacity and cooling efficiency is also a huge challenge (Xuezhen *et al.,* 2020; Tani Hub, 2020).

Land availability and security are fundamental to fulfilling the growing global demand for food. Land tenure security promotes investments in land and facilitates its productive allocation. Secure land rights make it easier to access credit by using land as collateral. In contrast, limited access to land and inadequate tenure security are crucial bottlenecks for farmers worldwide. This has tremendous consequences for agriculture. When farmers lack secure land rights, they are less likely to invest labor and capital in improving soil, growing perennial crops, managing rangelands, and building irrigation systems.

Access to machinery and equipment enables more efficient use of farm labor. However, investment in machinery is a major challenge for many small farmers, indeed an impossibility, given their limited financial resources. (Tani Hub, 2020). The use of IoT is accelerating, but challenges in harnessing this technology remain (Tani Hub, 2020).

Regulation-related challenges

The challenges related to regulation include law, policy, and governance issues in the agriculture industry. Some of the regulation-related challenges are issues related to governance and implementation of laws, anti-competitive practices, lack of a defined policy to minimize soil compaction practices, lack of proper land use regulations for agriculture, lack of transparency, government taxes and fees, lack of regulation to reduce gender bias and empower women, lack of key regulations to promote environmental sustainability, and so on. These challenges are discussed in detail in the following paragraphs.

The list of regulatory obstacles for agricultural producers is extensive. However, some types of regulations are particularly troubling. For example, any government intervention that makes it more difficult to manage the risks inherent in agriculture is a serious problem (Bakst, 2016). Additionally, the overreach and broad scope of environmental regulations inflict serious harm on farmers and ranchers alike. Finally, because technology and innovation help the agriculture industry meet critical new challenges, any regulation that hinders important developments is a major concern (Frelih-Larsen *et al.,* 2018).

Similar to their counterparts in every other business, agricultural producers face a number of serious risks. There are many ways that farmers and ranchers can manage different kinds of risks through private means. One of the best risk-management tools is to hedge risks through participation in the commodities market.

There is an urgency to reform agribusiness regulation for a variety of reasons. Some countries have outdated legal provisions that do not cater to farmers' needs. Other countries have prohibitive bureaucratic obstacles that stifle agribusiness processes (Department of Environmental Food and Rural Affairs, UK, 2015; FAO, 2017).

Farmers may want to expand the areas that they cultivate. Using machinery may be a viable option if adequate labor (of people and animals) is unavailable for planting, tending, and harvesting. However, registering agricultural machines can be complex. Most countries regulate tractors and require that agricultural tractors be formally registered before they are used. While registration serves an important purpose for ensuring basic safety levels, costly or time-consuming registration processes make it less viable for farmers to consider investing in agricultural machinery (World Bank, 2019; US Department of Agriculture, 2018).

Good quality seeds are essential inputs for farmers. Uncertified seeds comprise a comparatively large share of the seeds used by farmers globally and are often sourced through informal channels (World Bank, 2019). While farmer-based informal seed systems are vital for supporting biodiversity and resilience against climatic shocks, uncertified seeds may be of variable quality. For those farmers who decide to sell their produce on local, regional, or international markets, the availability of registered varieties and the quality of certified seeds are of paramount importance (European Commission *et al.,* 2021).

Fertilizer is used to increase agricultural productivity. Its appropriate use can bring higher crop yields, but adulterated fertilizer is rampant in many countries, damaging yields (World Bank, 2019). Additionally, some types of fertilizer may not be well adapted to local crops. Similar to the case of seeds, the consequences of using poor fertilizer may not become fully apparent until it is too late in the growing season for farmers to take action. Fertilizer testing, registration, and labeling requirements all ensure that good quality fertilizer is available to farmers. However, without a well-managed fertilizer registration system, registered fertilizers may not be widely accessible to farmers.

Women form a large part of the global agricultural labor force yet do not enjoy the same rights as men. Restrictions in accessing land, owning assets such as livestock or capital, and obtaining seeds and fertilizer make it harder for women to do business in agriculture (World Bank, 2019). Such constraints are often reinforced by poor laws. World Bank (2019) assesses some legal constraints that women face when pursuing transactions relevant for agricultural businesses, such as signing a contract, opening a bank account, or accessing credit. While there are only two countries, Cameroon and Niger, where women are not allowed to legally open a bank account in the same way as men, 54 out of 101 countries do not explicitly prohibit discrimination by creditors, on the basis of sex or gender, in their laws (Commonwealth of Australia, 2016; African Development Bank, 2010; US Department of Agriculture, 2018).

Enabling the Business of Agriculture aims to measure regulatory practices that contribute to safeguarding the long-term availability of the natural resources needed for agricultural production. Farmers need a healthy environment and adequate natural resources to grow food (World Bank, 2019). However, farming itself has impacts on water, soil, air, biodiversity, and overall ecosystem health. Considering the cross-cutting nature of environmental sustainability aspects, World Bank (2019) has integrated key practices into three indicators: supplying seed, securing water, and registering fertilizer indicators. Globally, regulation needs improvement to ensure that productivity does not come at a cost to the environment. Farmers need access to water or good quality fertilizer to produce crops and maintain livestock. Fertilizer may contain traces of heavy metals, which can accumulate in the soil and pollute surface water and groundwater, posing a threat to human and animal health. However, only half of the studied countries set a legal maximum for heavy metal content in fertilizer, and almost half of the studied countries do not regulate the management of runoff of water with excess fertilizer, chemicals, or salinity from agricultural fields (European Commission *et al.,* 2021; Tani Hub, 2020; US Department of Agriculture, 2018).

Low-income countries have the weakest performance on the registering fertilizer, supplying seed, and sustaining livestock indicators. Livestock can be one of the most important assets for farmers in developing countries, especially for those who lack secure land tenure. Livestock not only provides nutrition to families but also helps farmers—females in particular—obtain quick cash in cases of emergency or financial shocks. Moreover, animal diseases have a daunting impact on livestock farming revenues of farmers. In 1998 and 2000, Saudi Arabia and other Gulf states banned imports from Ethiopia due to an animal epidemic. As a result, the Somali Region, Ethiopia's main exporting

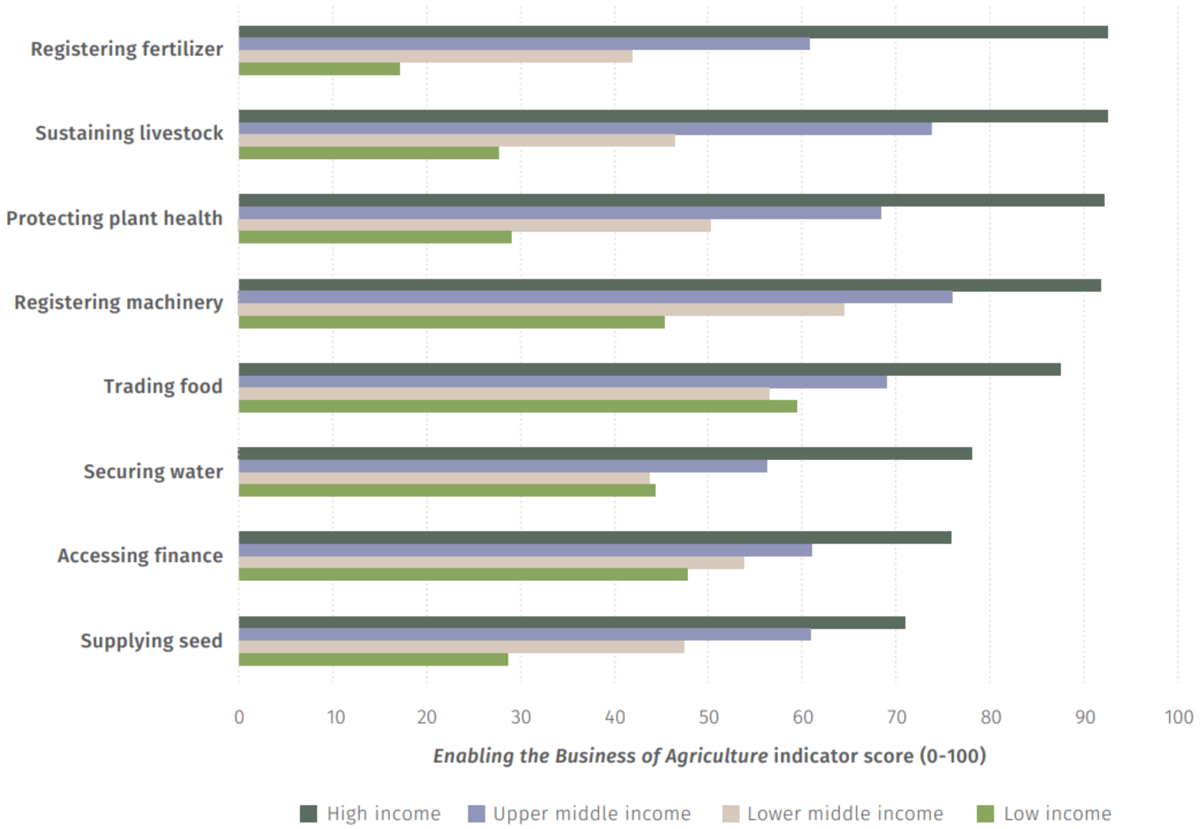


Figure 13. Average scores across eight indicators. The country sample includes 32 high-income, 19 upper middle-income, 27 lower middle-income, and 23 low-income countries.

Source: https://openknowledge.worldbank.org/bitstream/handle/10986/31804/9781464813870.pdf?sequence=7&isAllowed=y

region, experienced a 36% reduction in GDP compared with previous years (World Bank, 2019). Supplying seed is the most problematic area for farmers across all income groups (*Figure 13*).

The highest-scoring countries on the Enabling the Business of Agriculture indicators have regulations that cater to farmers' needs (*Table 3*). The three top-scoring countries are EU member states—France, Croatia, and the Czech Republic—which showcase good regulatory practices, as well as efficient administrative processes across number of indicators. France has implemented robust regulations on supplying seed, registering fertilizer, securing water, sustaining livestock, and protecting plant health. Croatia and the Czech Republic have efficient procedures for trading in agricultural products. In both countries, exporters are not required to obtain any license or agriculture-specific documents for each export shipment, and they can apply for a phytosanitary certificate online (World Bank, 2019).

Table 3. List of countries with aggregate scores in Enabling the Business of Agriculture

Source: https://openknowledge.worldbank.org/bitstream/handle/10986/31804/9781464813870.pdf?sequence=7&isAllowed=y

COUNTRY	SCORE	COUNTRY	SCORE	COUNTRY	SCORE
Afghanistan	31.52	Guatemala	65.11	Panama	72.91
Angola	27.05	Guinea	33.59	Peru	61.96
Argentina	76.00	Haiti	19.51	Philippines	68.03
Armenia	67.41	Honduras	49.13	Poland	86.00
Australia	82.73	Hungary	91.77	Portugal	89.82
Austria	89.57	India	62.23	Romania	85.73
Bangladesh	44.47	Iraq	22.62	Russian Federation	72.64
Belgium	87.68	Ireland	85.77	Rwanda	41.43
Benin	32.86	Italy	87.47	Senegal	43.98
Bolivia	58.75	Japan	83.96	Serbia	81.35
Bosnia and Herzegovina	71.82	Jordan	50.23	Sierra Leone	27.70
Brazil	75.25	Kazakhstan	68.01	Slovak Republic	91.55
Burkina Faso	35.30	Kenya	64.80	South Africa	68.73
Burundi	35.76	Korea, Rep.	65.09	Spain	91.71
Cambodia	35.95	Kyrgyz Republic	72.43	Sri Lanka	50.16
Cameroon	22.29	Lao PDR	37.10	Sudan	29.27
Canada	86.50	Liberia	16.42	Sweden	85.33
Chile	66.19	Lithuania	86.34	Switzerland	87.85
China	70.29	Madagascar	36.26	Tajikistan	43.19
Colombia	81.53	Malawi	41.51	Tanzania	57.15
Congo, Dem. Rep.	29.81	Malaysia	51.68	Thailand	58.51
Côte d'Ivoire	45.87	Mali	33.70	Togo	25.42
Croatia	92.68	Mexico	69.46	Tunisia	39.52
Czech Republic	92.32	Morocco	64.02	Turkey	78.18
Denmark	86.03	Mozambique	50.97	Uganda	52.15
Dominican Republic	50.00	Myanmar	31.27	Ukraine	67.40
Egypt, Arab Rep.	47.06	Nepal	48.97	United Kingdom	88.87
Ethiopia	46.12	Netherlands	90.69	United States	88.76
Finland	86.67	New Zealand	89.30	Uruguay	65.50
France	93.70	Nicaragua	69.92	Uzbekistan	41.62
Georgia	63.53	Niger	29.39	Vietnam	61.41
Germany	89.14	Nigeria	49.17	Zambia	63.73
Ghana	50.49	Norway	84.57	Zimbabwe	48.36
Greece	88.57	Pakistan	48.87		

Seventeen of the top 20 countries are in Europe. However, no country has reached the best possible regulatory benchmark on all indicators measured by Enabling the Business of Agriculture. All governments have room for improvement of their laws, regulations, and bureaucratic processes that affect domestic farmers (World Bank, 2019).

SCM and logistics-related challenges

The challenges related to SC and logistics cover both SC issues and logistical transport and storage issues concerning agricultural products. In the SC, the challenges are related to collaboration among stakeholders, information management, coordination, leadership issues among farmers and market traders, and so on. These challenges include high supply–demand mismatch, distrust among stakeholders, inadequate post-harvest management infrastructure, poor post-harvest management, lack of transparency, lack of a coordinated SC, highly fragmented industry with multiple intermediaries and so on. The logistical part includes the transport of agricultural products from farms to storage houses and warehouses, among others. The challenges consist of inadequate post-harvest management infrastructure, uneven distribution of storage facilities, poor post-harvest management, high SC cost, agricultural waste and loss, lack of proper transport facilities, poor packaging practices/standards, poor handling, high cost of using cold chains, lack of cold chain facilities, and so on. The SC and logistic issues are discussed in detail in the following paragraphs.

Current market structures separate farmers from their end market, making it difficult for them to take into account the infrastructure and the end market, which can lead to mismatches in the volume of production, time of planting, cultivars planted, and time of harvest, all of which influence food waste levels (Parfitt *et al.,* 2021). Additionally, market practices frequently maintain asymmetric power balances, which favor markets over farmers. In many SCs, this weakens the farmers' abilities to negotiate and reduces their incomes, making it more difficult to break the cycles of poverty and invest in training and technology to reduce food waste (OECD/FAO, 2016; Berg *et al.,* 2016).

In 2011, a FAO study reported that roughly one-third of the global food produced for human consumption is lost or wasted, which amounts to about 1.3 billion tons per year, worth nearly US$ 1 trillion (Easdown and Acedo, 2015). Food losses amount to US$ 310 billion annually in developing countries, where nearly 65% of food losses occur at the production and post-harvest stages. In the Asia-Pacific region, 15–50% of food crop output is lost between the production and marketing stages (Easdown & Acedo, 2015; OECD/FAO, 2016).

Food loss means damage and spoilage from the producer to the market, including the lack of management during harvest, in packaging, in transit, and in storage. Food waste on farms remains neglected in comparison to efforts targeting retail outlets and households. This is partly due to the complexities in measuring the farm-stage waste, creating difficulty in measuring progress in reductions and an underestimation in the significance of its contribution to food waste levels (Julian Parfitt *et al.,* 2021; Asian Development Bank *et al.,* 2016).

The relative lack of focus on the farm-stage food waste also results from the perception that it is a more significant issue in lower-income countries, due largely to a lack of access to technology, such as cooling facilities. Subsequently, past interventions tended to focus on technical solutions, addressing issues with farm technology or storage, while largely ignoring socioeconomic and market factors that shape the agricultural system (Parfitt *et al.,* 2021).

However, the report of Parfitt *et al.* (2021) shows that food waste at the farm level is driven by a multitude of human factors and decisions at the later stages of the SC—while waste in the SC is often driven by changeable factors at the farm level. Interventions targeted at the environmental and biological drivers of food losses are unlikely to succeed until they are supported by changes in the human elements of the SC (Parfitt *et al.,* 2021; Asian Development Bank *et al.,* 2016).

In developing countries, most food losses occur after the crop harvest, between the field and the market. However, the specific causes of post-harvest loss vary widely, depending on the crop type, region, culture, weather, and farmers' incomes. While there is no single root cause of post-harvest loss, a number of proposed challenges identify three key issues: poor storage, lack of training, and limited data (US Department of State, 2013).

The quality decay of the products during transportation also needs to be mentioned. Even though the transportation time in the first mile is comparably shorter than that for linehaul transportation, poor first-mile transportation conditions can also severely damage the product quality (Asian Development Bank *et al.,* 2016). In fact, in the ideal situation, cold chain logistics should start from first mile stage especially for perishable products. Even a small period of cold chain disruptions can lead to serious quality problems for the products on consumers' hands. Unfortunately, the proportion of refrigerated transportation in the first mile is extremely low in most countries. Combined with the low-technology and low-density cold storage, the initial product quality delivered by the first-mile logistics is very low, which imposes substantial challenges on the remaining operations in the SC due to the "rubbish-in-rubbish-out" effects (Parfitt *et al.,* 2021; Easdown and Acedo, 2015; US Department of State, 2013).

Proper packaging is important for agricultural logistics because it facilitates handling products as they are transported between markets and collection points. Along the so-called first mile of agricultural logistics, where food moves from farms to local wholesale markets, farm products are seldom packaged at all. If they are, inferior packaging methods are used. This leads to increased spoilage, damage, and potential food safety hazards (Asian Development Bank *et al.,* 2016). In addition to shortfalls in the use of modern packaging methods, there are no widely adopted packaging standards for fruits, vegetables, and meat products. Different packaging standards are used at different points along the SC, and this lack of standards interrupts the flow of goods from one point in the SC to another as goods are unloaded and repackaged (Van Dusen and Beyard, 2013; US Department of State, 2013; Xuezhen *et al.,* 2020).

Most farmers lack knowledge of or access to information on appropriate post-harvest handling practices. Some farmers join farmer organizations to aggregate their products and to find better markets. Unfortunately, many farmer organizations are poorly managed, and the members themselves are unable to produce quality products that meet the specifications of better paying buyers (Van Dusen and Beyard, 2013; International Labour Organization, 2017; OECD/FAO, 2016).

Economics, business, and finance-related challenges

The challenges related to economics, business, and finance cover the cost and monetary-related challenges to agriculture and first-mile logistics. These include transport economics, business model issues, investment-related challenges, and market system challenges for agriculture, business, and first-mile logistics. The list of challenges includes SC cost, increased freight trucking prices, high fuel cost, high labour cost, long and multi-layered SCs, complex SCs, lack of proper marketing, fertilizer quality, high-interest loans for non-bankable farmers, high taxation on agriculture-related products, anti-competitive practices, lack of proper marketing, market access issues, and so on. The challenges are discussed in detail in the following paragraphs.

SC costs are driven by the standard of infrastructure used and the crop/commodity being transported. It is difficult to compare the SC costs for each commodity due to the differences in measurement. The transport costs in developing countries are very high, and those in African nations are among the highest in the world, reaching as much as 77% of the value of exports (Department of Infrastructure and Regional Development, 2017; African Development Bank, 2010).

To ensure that fresh fruits and vegetables in the circulation of all links are always maintained in the required low-temperature conditions, it is necessary to install temperature control equipment and use refrigerated vehicles or low-temperature warehouses. At the same time, to improve the efficiency of logistics operations, advanced information systems and technology must be adopted.

The surge in gas prices continues to pose a serious challenge for the EU fertilizer industry, curtailing the production of nitrogen fertilizers, where natural gas is largely used as feedstock in the production process. Fertilizer prices in March 2022 were 227% higher than in December 2019 compared with a 109% increase in energy prices over the same period (European Commission, 2022).

The agriculture sector needs structured and functional markets, preferably in the vicinity of farmers, to drive growth, employment, remunerative prices, and economic prosperity in rural areas of a country. Enabling mechanisms are also required to procure agricultural commodities directly from farmers' fields and to establish an effective linkage between farm production, the retail chain, and food processing industries. To remove restrictive and monopolistic practices of the present marketing system, reduce the intermediaries in the SC, decrease wastage by way of promoting an integrated supply and value chain, and benefit farmers through access to global markets, reforms in agricultural markets have to be perceived as an ongoing process. The agriculture sector needs competitive and well-functioning markets for farmers to sell their produce. There is a need to enhance private-sector investment in the development of post-harvest marketing infrastructure, for which various schemes have also been implemented by the Government of India (Ministry of Agriculture and Reforms, India, 2021).

Lack of security is a key obstacle for farmers to access credit in order to invest in production. In developing countries, land is the most common form of collateral (guarantee) used to secure financing. However, some farmers have problems with demonstrating their clear legal rights to their lands (Tani Hub, 2020). In countries where regulatory frameworks recognize the use of warehouse receipts as an alternative movable collateral, farmers can receive a warehouse receipt as evidence of deposited goods. A warehouse receipt serves to fulfill collateral requirements and enables farmers to obtain credit, particularly working capital. Furthermore, a reliable warehouse receipt system allows farmers to extend the sales period of perishable products beyond the harvesting season when prices are usually low. This system increases income for farmers and stabilizes market prices over the long term (Giovannucci *et al.,* 2012; Angelucci *et al.,* 2013; FAO, 2017).

Access to market information is lacking. Where opportunities exist, farmers can rarely take advantage of them because they are not empowered or sufficiently informed. Extension systems are in crisis; the staff members are aging and have limited mobility, few incentives, or inadequate modern technological knowledge and acumen. The government generally lacks the capacity to resolve these issues (African Development Bank, 2010). One of the main issues in the commodity market structure is generally characterized by the lack of market linkages and access. This means limited opportunities for adding value by post-harvest processing, as well as high post-harvest losses, which are estimated at 30% for grains and 50% for other more rapidly perishable products (African Development Bank, 2010; Angelucci *et al.,* 2013; Ministry of Agriculture and Reforms, India, 2021).

Natural environment and phenomena-related challenges

Soil compaction affects soil functions and soil ecosystem services, including crop yield. While natural processes and tillage can ameliorate topsoil compaction, compaction of the subsoil (i.e., the layer below the normal tillage depth) is persistent and should be prevented. Due to the increasing size and weight of the field machinery used in European agriculture, there is a growing risk of persistent damage to the subsoil. Between 1960 and 2010, wheel loads from machinery increased by almost 600%. RECARE work indicates that approximately 29% of subsoils across Europe are already affected by subsoil compaction. Subsoil compaction results in substantial losses of ecosystem services. The long-term annual loss in agricultural yield has been estimated at 6% or well over €1 billion a year across Europe. The threat of subsoil compaction is systemic in nature. Having to balance different considerations, including profitability, efficiency, weather, labor, and timing when planning their field traffic, farmers rarely prioritize preventing subsoil compaction. The costs of preventive measures are not rewarded by immediate benefits, as such measures are costly. It may still be more profitable for farmers to use heavy machinery and compact the subsoil than adopt preventive measures (Frelih-Larsen *et al.,* 2018).

Soil compaction is a major threat to European agriculture, due to the structural and technological developments in agriculture since the Second World War, which have led to increasingly large and heavy field machinery. To ensure fieldwork efficiency and remain competitive in food markets, farmers have adopted ever-larger machinery. This has resulted in increasing loads on the soil, and since subsoil compaction is primarily determined by the wheel load, such compaction has grown dramatically in recent years. Based on historical data, it has been estimated that the typically used wheel loads increased from around 1.5 to 8.7 Mg in the period 1960–2010 or by 600%. As a result, the mechanical stress reaching subsoil layers from typically used machinery has increased by a factor of two for upper subsoil layers to as much as a factor of five for deep subsoil layers over the same period, thereby exceeding soil mechanical strength even at moderately wet soil conditions (Petersen and Abrahamsen, 2021).

Soil compaction has a strong negative impact on crop yield and a range of other ecosystem services provided by uncompacted soil. While topsoil compaction is reversible, subsoil compaction is effectively persistent, cumulative, and invisible on the surface. Therefore, subsoil compaction should be prevented. Soil compaction implies a reduction in crop yield. Experiments have shown that high-wheel-load traffic in wet conditions inflicts long-term yield penalties in the range of 6–12%. In the field, this means yield losses of 6% in small grain cereal production or losses in product value amounting to €97 million in Denmark, €487 million in Germany, and €713 million in France (Isbister *et al.,* 2013; Stolte *et al.,* 2016; Department of Environmental Food and Rural Affairs UK, 2015).

Subsoil compaction also affects a range of other ecosystem services. It reduces the buffer capacity and filter function of the soil, thereby increasing the risk of pollutants leaching to the aquatic environment. It increases the risks of surface runoff and soil loss by erosion as well, and it may elevate greenhouse gas (GHG) emissions. Finally, the soil is a very complex biophysical material that performs a range of processes. Therefore, subsoil compaction may cause unintended effects that extend beyond the farmgate and into the future. Subsoil compaction is thus a wicked problem that is not necessarily solved through market forces (Petersen and Abrahamsen, 2021; Frelih-Larsen *et al.,* 2018).

Climate change is very likely to affect food security at the global, regional, and local levels. Climate change can disrupt food availability, reduce access to food, and negatively affect food quality (Fakava, 2012). For example, projected increases in temperatures, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability may all result in reduced agricultural productivity. Increases in the frequency and severity of extreme weather events can also interrupt food delivery, and the resulting spikes in food prices after extreme events are expected to be more frequent in the future. Increasing temperatures can contribute to spoilage and contamination (Fakava, 2012).

Adverse impacts of climate change are already being felt across Europe. Extreme weather, including recent heatwaves in many parts of the EU, are already causing economic losses for farmers and for the EU's agriculture sector. Future climate change might also have some positive effects due to longer growing seasons and more suitable crop conditions, but these benefits will be outweighed by the increase in extreme events, negatively affecting the sector (Kurnik, 2019).

Climate impacts have led to poorer harvests and higher production costs, affecting the price, quantity, and quality of farmed products in parts of Europe. While climate change is projected to improve conditions for growing crops in parts of northern Europe, the opposite is true for crop productivity in southern Europe. According to projections using a high-end emission scenario, yields of non-irrigated crops such as wheat, corn, and sugar beet are projected to decrease in southern Europe by up to 50% by 2050. This could result in a substantial drop in farm income by 2050, with large regional variations (Kurnik, 2019; Giovannucci *et al.,* 2012; Stolte *et al.,* 2016).

In a similar scenario, farmland values are projected to decrease in parts of southern Europe by more than 80% by 2100, which could result in land abandonment. Trade patterns could also be impacted, which would in turn affect agricultural income. While food security is not under threat in the EU, increased food demand worldwide could exert pressure on food prices in the coming decades (Kurnik, 2019; Isbister *et al.,* 2013).

A recent study under the Peseta III project analyzed the propensity for damage from drought, based on future changes in soil moisture conditions and the current economic and population conditions. In the period 2021–2050 compared with 1981–2010 (using the 2 °C scenario), the drought hazard is projected to significantly increase in southwestern Europe and mostly decrease in central Europe (Kurnik, 2019).

Farmers also need access to water, and regulation affects this. Water is a critical resource, and its shortage is often a source of risk for farmers. When farmers perceive high risks from insufficient water, they must make strategic decisions. Their possible options include growing crops or raising animals that require less water, investing in storing rainwater on farms to be able to survive dry spells, or pumping groundwater or drawing water from nearby ponds or streams. Each of these choices brings its own risks. Farmer-led irrigation development, if the scale is large enough, may require complying with water use permit rules. Even when farmers are exempt from regulatory requirements, it can be a dubious benefit, as the lack of regulation signifies that their water use may not be well protected (either legally or practically) against other major water users. If a farmer invests in irrigation and the local water source becomes polluted or depleted, there could be few options left. Too little water means reductions in harvest, in the growth of farm animals, and in farm revenues (OECD/FAO, 2016; Isbister *et al.,* 2013; FAO, 2015; Fakava, 2012; African Development Bank, 2010).

Pests and diseases pose great risks to crops. These outbreaks can spread rapidly and lead to significant crop losses—compromising the abilities to produce robust harvests, deliver on production contracts, or meet market standards. It is estimated that plant diseases destroy 10% of the world's crop harvest. Farmers must rely on strong phytosanitary legislation that allows rapid pest identification, reporting, and quarantine (FAO, 2015; Fakava, 2012).

There is limited access to improved seed and livestock and to the appropriate technology to increase the output of labor and to reduce drudgery. The lack of credit to access inputs at reasonable prices limits farmers. Only a limited number of crops and livestock products are produced for the market, despite the varieties of livestock and crops that have evolved over time in Africa. Very low prices for products on local, national, and international markets limit farmers' ability to get ahead without credit (OECD/FAO, 2016; Isbister *et al.,* 2013; FAO, 2015; African Development Bank, 2010).

Climate change has both direct and indirect impacts on agricultural production systems. Direct impacts include effects caused by modifications of physical characteristics, such as temperature levels and rainfall distribution on specific agricultural production systems. Indirect effects are those that affect production through changes on other species, such as pollinators, pests, disease vectors, and invasive species. These indirect effects can play a major role. They are much more difficult to assess and to project, given the high number of interacting parameters and links, many of which remain unknown (FAO, 2015; African Development Bank, 2010).

Rainfall is often unreliable, and the effects of drought are aggravated by fragile soils with low water-holding capacity. Water and soil conservation measures, often based on indigenous knowledge, have been identified, but there has been a lack of investment to put these into effect over large areas. In Asia, the percentage of areas under irrigation has grown from 25% to 41% compared with less than 4% in Africa. There is huge potential to increase irrigation in dry areas and partial water control in more humid areas (Easdown and Acedo, 2015; African Development Bank, 2010).

Summary

Table 4. Summary of findings from gray literature review

Clusters	References	Issues and challenges
1. Infrastructure		
1.1. Physical 1.1.1. Road Network	US Department of State, 2013; Banjo *et al.,* 2012; Ludwig *et al.,* 2016; Iimi *et al.,* 2015; European Union, 2017	Inadequate post-harvest management infrastructure, lack of adequate drainage systems and road maintenance, poor physical road network, poor rural accessibility, poor access to farmland, lack of cold chain facilities, lack of ripening facilities for crops (e.g., banana, watermelon, mango, etc.)
1.1.2. Storage and Warehouses	US Department of State, 2013; Xuezhen *et al.,* 2020; Tani Hub, 2020; Government of India, 2019; Iimi *et al.,* 2015; Easdown and Acedo, 2015	
1.2. Digital		High telecommunication costs, inefficient tracking system, lack of advanced technologies, lack of access to machinery and equipment
1.2.1. Communication Network	Banjo *et al.,* 2012; Tani Hub, 2020	
1.2.2. IoT	Banjo *et al.,* 2012; Gray *et al.,* 2018	
1.2.3. Others	Gray *et al.,* 2018; Tani Hub, 2020 Davidova and Thomson, 2014	
2. Regulatory Issues	Food and Agriculture Organization (FAO), 2017 Angelucci *et al.,* 2013; Frelih-Larsen *et al.,* 2018; Department of Environmental Food and Rural Affairs UK, 2015 Commonwealth of Australia, 2016; European Commission *et al.,* 2021 OECD/FAO, 2016; Tani Hub, 2020; Kirubi and Burrows, 2015; US Department of Agriculture, 2018	Issues related to governance and implementation of laws, anti-competitive practices, lack of defined policy to minimize soil compaction practices, lack of proper land use regulations for agriculture, lack of transparency, government taxes and fees, lack of regulation to reduce gender bias and empower women, lack of key regulations to promote environmental sustainability
3. SCM and Logistics		
3.1. Supply Chain 3.1.1. Collaboration	OECD/FAO, 2016; Berg *et al.,* 2016	Lack of coordination among partners, high supply–demand mismatch, maintenance of documents for certification, distrust among stakeholders, inadequate post-harvest management infrastructure, poor post-harvest management, lack of transparency, lack of coordinated supply chain, highly fragmented industry with multiple intermediaries
3.1.2. Information Management	International Labour Organization, 2017; OECD/FAO, 2016	
3.1.3. Coordination and Leadership Issues	Kirubi and Burrows, 2015; US Department of State, 2013; OECD/FAO, 2016; Tani Hub, 2020; Government of India, 2019; Berg *et al.,* 2016	
3.2. Logistics 3.2.1. Transport Issues	US Department of State, 2013; Xuezhen *et al.,* 2020; Ludwig *et al.,* 2016; Kirubi and Burrows, 2015; Department of Infrastructure and Regional Development, 2017; Parfitt *et al.,* 2021; Easdown and Acedo, 2015	Inadequate post-harvest management infrastructure, uneven distribution of storage facilities, poor post-harvest management; high supply chain cost, agricultural waste and loss, lack of proper transport facilities, poor packaging practices/standards, poor handling, high cost of using cold chains, lack of cold chain facilities
3.2.2. Storage and Warehouses i) Packaging and material handling	Asian Development Bank *et al.,* 2016; US Department of State, 2013; Xuezhen *et al.,* 2020; Parfitt *et al.,* 2021; Van Dusen and Beyard, 2013	
ii) Storage facilities	Parfitt *et al.,* 2021; Department of Infrastructure and Regional Development, 2017; Xuezhen *et al.,* 2020; Tani Hub, 2020; Easdown and Acedo, 2015	
4. Economics; Business and Finance		
4.1. Transport Economics 4.1.1. Transport Costs	Department of Infrastructure and Regional Development, 2017; US Department of Transportation, 2022	Supply chain cost, increased freight trucking prices, high fuel cost, high labor cost
4.1.2. Other Cost Issues	Tani Hub, 2020	
4.2. Business Models 4.2.1. Business Case Issues	Tani Hub, 2020; Government of India, 2019	Long and multilayered supply chain, complex supply chain
4.3. Investment	Tani Hub, 2020	Lack of proper marketing, poor fertilizer quality high-interest loans for unbankable farmers
4.5. Market Issues	Angelucci *et al.,* 2013; OECD/FAO, 2016; Tani Hub, 2020; Berg *et al.,* 2016; Ministry of Agriculture and Reforms, 2021	High taxation on agriculture-related products, anti-competitive practices, lack of proper marketing, lack of market access
5. Natural Environment and Phenomena		
5.1. Soil Compaction	Frelih-Larsen *et al.,* 2018; Department of Environmental Food and Rural Affairs UK, 2015; Isbister *et al.,* 2013; Stolte *et al.,* 2016; Petersen and Abrahamsen, 2021	Lack of defined policy to minimize soil compaction practices, soil erosion, water erosion issues, soil compaction threats
5.2. Extreme Weather	Isbister *et al.,* 2013; Giovannucci *et al.,* 2012; Stolte *et al.,* 2016; Kurnik, 2019; Fakava, 2012	Soil erosion, wind erosion, water scarcity, climate-related challenges, changes in soil moisture and temperature
5.3. Others	OECD/FAO, 2016; Isbister *et al.,* 2013; FAO, 2015; Fakava, 2012; African Development Bank, 2010	Lack of environmentally friendly practices, fertilizer quality, leaching issues, climate change issues, irregularities in temperature and rainfall, pests and diseases, saline intrusion into freshwater, increased flooding, lack of quality seed
6. Skill Set and Workforce	Easdown and Acedo, 2015; African Development Bank, 2010	Lack of knowledge, inadequate manpower and poor skills, gender equality and women's empowerment issues

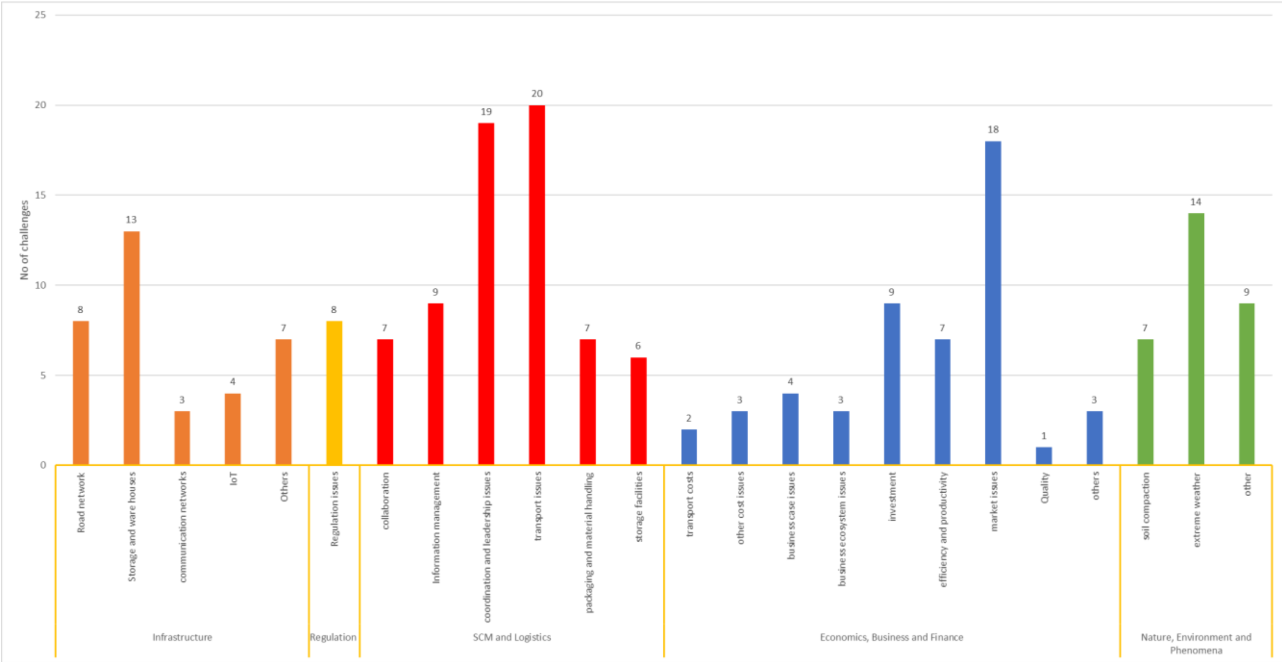


Figure 14. Number of challenges in each category

3.1.3. Other sources

Other sources included selected project reports and materials, website information, blogs, professional magazines, and typically materials that had not been formally peer-reviewed and could not be necessarily regarded as official data or information. However, in some places, the division among scientific literature, grey literature, and other sources is not entirely clear, but this ambiguity was deemed to be not critical.

RECARE project

The European Commission funded the RECARE project (Preventing and Remediating Degradation of Soils in Europe through Land Care, under which several case studies were conducted around Europe. The case study dealing with first-mile and field operation issues was undertaken in Aarslev, Denmark, focusing on soil compaction caused by moving work machines on the field. In the Aarslev case, the researchers studied the wheel load and inflation pressure of machine tyres and their impact on soil compaction. The rubber tracks' effect on soil compaction was also compared with traditional tyres' impact. The results noted two main directions: 1) vertical stress of tyres versus tracks and 2) shear forces of the two traction systems. A special concern observed in the project was subsoil compaction (i.e., beneath the immediate surface).

Figure 15. Tractor on the field

The RECARE project also produced extensive map data on soil conditions and risks of soil and land deterioration (http://www.recare-hub.eu/soil-threats/compaction). The project also delivered some relevant scientific publications (Schjønning *et al.,* 2015; Schjønning *et al.,* 2016; Schjønning *et al.,* 2017; Obour *et al.,* 2017; Lamandé *et al.,* 2017).

Another issue that touched on first-mile problems was soil erosion, which had two main implications: loss of field soil fertility and destruction of road infrastructure.

First-mile and traffic safety

Agri-work machines are large and heavy, and they disrupt the traffic flow on roads when being driven to, from, and between operation sites. However, several studies indicate that the safety issue is perhaps not critical when compared with other causes of road accidents. For example, the UK Department of Transport recorded 1,870 road fatalities and 27,820 people killed or seriously injured, as reported to the police between January and June 2019 (https://www.gov.uk/government/statistics/reported-road-casualties-in-great-britain-provisional-estimates-year-ending-june-2019). In 2018, agricultural vehicles were involved in 488 accidents, with 29 fatalities. Thus, the role of agri-machines in road accidents is marginal (https://www.fwi.co.uk/machinery/tractors-road-rights-wrongs-rules-regulations).

Työtehoseura (an independent national training, research, and development organization in Finland) studied road accidents with slow-moving vehicles, covering the period 2004–2014. Most of the accidents (275) involved tractors. Harvesters had been involved in two accidents only (Tuure *et al.,* 2016).

The typical mitigation measures against the risks of work machine-induced accidents on roads include the following:

- Recommendations to machine operators
  - Not holding up long queues behind the machines (UK recommendation: not more than six cars behind the machine before pulling over)
  - Pulling over only when it is safe
  - Route selection
- Regulations
  - Dimensions, including weight, of machines that are allowed to be driven on public roads

    - Licensing of machine drivers (age, training); in many countries (e.g., in some states in the US), even children are allowed to drive a tractor (FarmProgress, April 5, 2017).
    - Speed limits (usually, the larger and heavier the machine, the lower the allowed maximum speed)
    - Inspections and trafficability regulations; for example, the Republic of South Africa has an official standard for testing and certifying road worthiness. Most advanced countries have similar regulations, and the EU covers some equipment, such as tractors (motor vehicles exceeding road speeds of 25 km/h), via Directive 2014/45/EU; however, some exceptions are allowed, such as for AF machines.
- Technical solutions
    - Increasing the safe road speed capability in order to reduce the speed difference between the machine and rest of the traffic flow
    - Modular vehicle design so that the machine or machine combination dimensions can be reduced to better fit the road space

However, the general trend is that machines tend to be larger, heavier, and more powerful and that regulations must somewhat follow these trends (i.e., allow larger and heavier machines to be driven on public roads). Recently, new regulations on road trafficability of farming machines were introduced in Italy (Mondo Macchina/Machinery World, November 2021, by editorial staff).

The European Agricultural Machinery Association (CEMA) works toward a harmonized road trafficability regulation for the EU (https://www.cema-agri.org/about-cema). Currently, self-propelled agricultural machinery, such as self-propelled sprayers or combined harvesters, needs to meet technical requirements before they are allowed to be driven on the road. In the internal market, each CEMA member state in Europe is entitled to define its own rules to ensure an appropriate level of safety for mobile machines circulating on public roads.

Standards

Most advanced countries have standards and regulations regarding the work machines used in AF (or any other sector). The United Nations Economic Commission for Europe (UNECE), the OECD, and ISO have several sets of standards that also concern AF machines, such as the following:

- UNECE Regulation No. 106, covering the categorization of pneumatic tires
- ISO 3776 set of requirements on seat belt assemblies
- OECD set of Tractor Codes

It is not entirely clear how the regulations and standards are diffused into national regulation systems, but expectedly, there will be substantial variations among different countries.

Decarbonizing agri-machinery

About 1% of the total EU27 GHG emissions can be attributed to agricultural machines' combustion engines. The most promising strategies identified by CEMA (2022) comprise alternative fuels that are adaptable to combustion engine technology and optimize the operating and logistic processes.

	Potential options for CO_2 reduction in agriculture using machinery	Energy efficiency gains in crop production	CO_2 reduction potential	Low need for investment in vehicle adaptation and/or infrastructure on farm/in-field	Return on investment for farmers (cost vs CO_2 reduction - mid-term 2030)	Applicable fleet
ALTERNATIVE FUELS	Sustainable biomass fuels	Not applicable		Low cost for vehicle design and infrastructure (case dependent)		Existing fleet (case dependent) & New fleet
	Synthetic fuels (not available yet)	Not applicable		Current engines can be used		Existing fleet & new fleet depending on fuel availability
ALTERNATIVE DRIVES	Full electric powertrain with **battery** (source: renewable energy only/carbon capture)	High efficiency of the powertrain		High cost for vehicle design, less for infrastructure		New fleet (limited power range) & Future fleet
	Full electric powertrain with H_2 - **fuel cell** (source: renewable energy only)	High efficiency of the powertrain		High cost for vehicle design and for infrastructure on farm		New fleet (limited power range) & Future fleet
	Hybrid electrification in combination with ICE		Due to e-implements	Current engines can be used		Existing fleet with add-ons & New fleet
ENERGY EFFICIENCY OPTIMISATION METHODOLOGIES	Towing machine optimisation (drivetrain)	Additional efficiency gains are low		High cost for vehicle design		New fleet
	Towing machine + implement use optimisation within the process and the process chain			It is about ongoing process optimisation		Fleet independent

- Clearly negative potential
- Somewhat negative potential
- Neutral/ difficult to assess/Not applicable
- Somewhat positive potential
- Clearly positive potential

Figure 16. CEMA (2022) assessment for different options to decarbonize agri-machine operations

Source: https://cema-agri.org/images/publications/position-papers/CEMA_decarbonising_agriculture_27-04-22.pdf

Summary

Table 5. Summary of findings from reviewing other sources.

Clusters	References	Main Issues
1. Infrastructure		
1.1. Physical		
1.1.1. Road Network	Professional magazines; miscellaneous statistics; Tuure *et al.,* 2016	Road safety
2. Regulatory Issues	OECD, ISO, EC	Multiple, fragmented standards and standardization bodies; uncertainty of national adoption speed and coverage
5. Natural Environment and Phenomena		
5.1. Soil Compaction	RECARE project; Schjønning *et al.,* 2015; Schjønning *et al.,* 2016; Schjønning *et al.,* 2017; Obour *et al.,* 2017; Lamandé *et al.,* 2017	Soil compaction, subsoil compaction, field traffic
5.3. Others	CEMA, 2022	Climate change, decarbonization of machine operations

3.1.4. Hierarchical structure of challenges

The complete problem/hierarchy tree structure of challenges is visualized below. The structuring logic is dependent on the keyword selections used in the information search and the insights of the project partners and researchers on the task. Therefore, the result is just one of the possible outcomes and is regarded as 'good' if it succeeds in isolating and differentiating the challenges from one another. It is by no means the only possible outcome nor necessarily the optimal one for all purposes. The validity is always relative and dependent on the user and how well the structure responds to the need at hand.

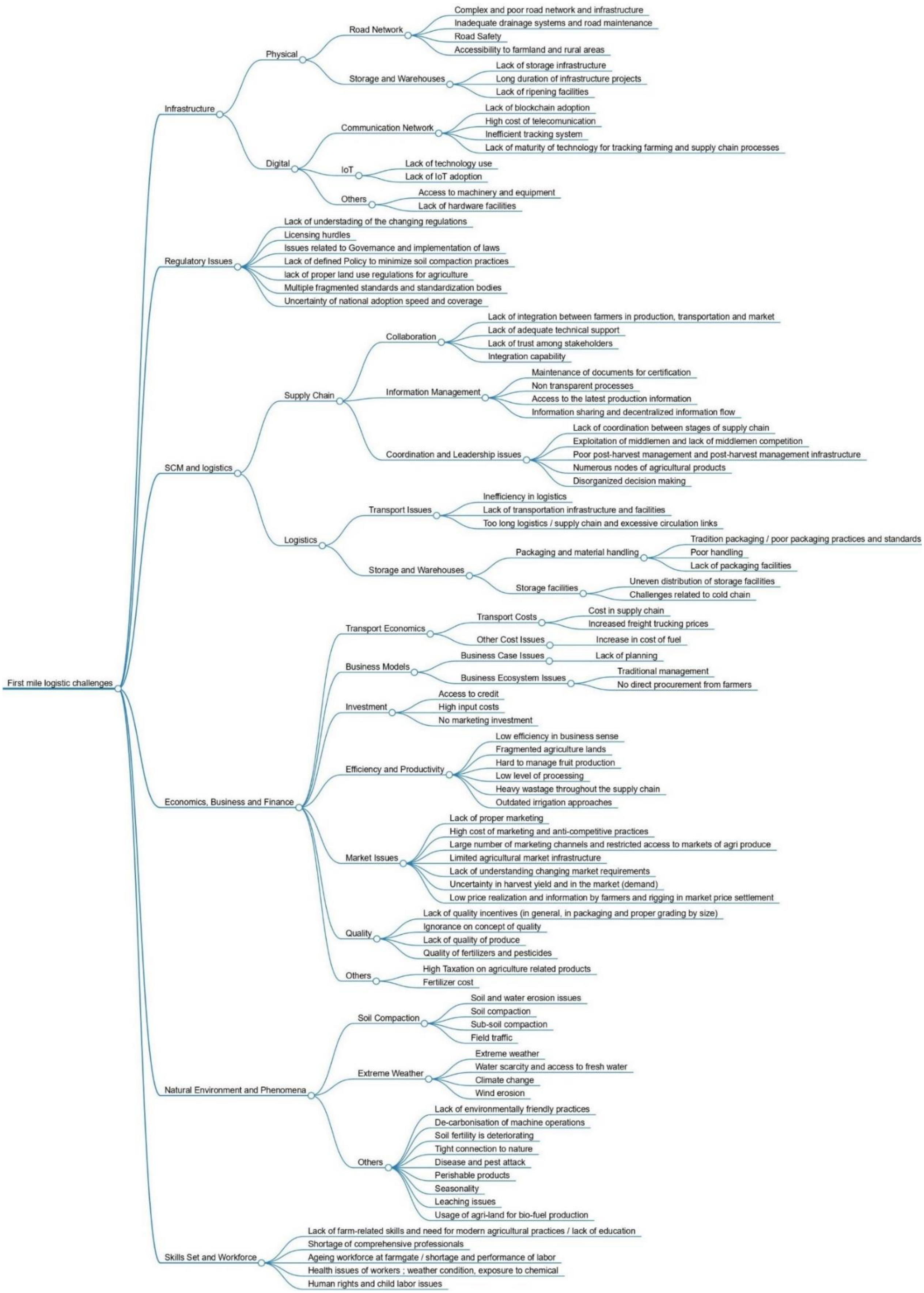


Figure 17. Tree diagram of challenges

3.2. Results from industrial partners and expert interviews

3.2.1. Industrial partners

The four industrial partners of the LEVITOI project, all from Finland and mostly export-oriented, were interviewed in April 2022. They were asked about the challenges in the industry, in the context of first-mile challenges of primary production, from their perspectives as machinery providers and consultants.

Table 6. Companies (Industrial partners) and codes

Company	**Type**
Company A	Seeder
Company B	Tyre Producer
Company C	Harvester
Company D	Consultancy

Because the companies provide different services and products, their presented challenges differ accordingly (*Table 6*). *Company C* noted wet and sticky soil during harvesting, as well as how to be certain about regulations for machine development, as challenges. Hilly agricultural areas and upland rice fields were found to be worth focusing on by Company C as a harvester. Overall, its distinct challenges were mostly topography-related issues.

Table 7. Challenges identified by the industrial partners

Challenge	Industrial Partner
Climate change	Company A
Different process requirements for different regions	Company A
High cost of petrol	Company A
Lack of moisture for seeding	Company A
Poor quality of fertilizers	Company A
Uncertainty in international politics	Company A
High cost of equipment	Company C
Lack of information at farmgate about available products	Company C
Lack of information on using the equipment correctly and resistance to learning	Company C
Mismatch between customer requirements and machine features	Company C
Resistance to digitalization	Company C
Contrasting needs for the machines, aka wide or narrow tires	Company B
Different regulations in different countries	Company B
Lack of proper equipment	Company B
Lack of regulation on soil compaction, leading to confusion	Company B
Uncertain weather, more uncertain in the north	Company B
Small-scale farms	Companies B and C
Limited access to lower-level street network in other countries	Company D
Soil compaction	Companies A, B, and C

For *Company A*, as a seeder provider for the industry, its concerns were mostly related to technical agricultural issues, for instance, how to increase the productivity of seeding and improve the quality of fertilizers. It was noted that the soil was dry and compact for seeding. Another area of focus was how to manage and be guided by highly varied process requirements in different regions around the world.

One of the major concerns of *Company B* was communicating product information to its customers in a better way, how to make farmers more aware of its available products, and how to engage them in the product development process. Since *Company D* provides consultancy about road networks, it was concerned about how to obtain information about lower-level street networks in countries other than Finland.

Overall, we can confidently summarize that the first common challenge comprised how to cause less soil compaction with machines, how to improve machineries in order to cause less soil compaction, and what the regulations were in relation to the mentioned issue. The second challenge was about how the road regulations were around the world and how the organizations could align their products to fit the regulations.

The discussions with the industrial partners in April 2022 directed us to create *Figure 18*. The main challenges noted by them were categorized, intersections were determined, and their locations on the ASC are presented in the figure. It was inferred from the interviews that at the first-mile stage of the SC, circular transportation can often occur; thus, sequential SC figures require updates.

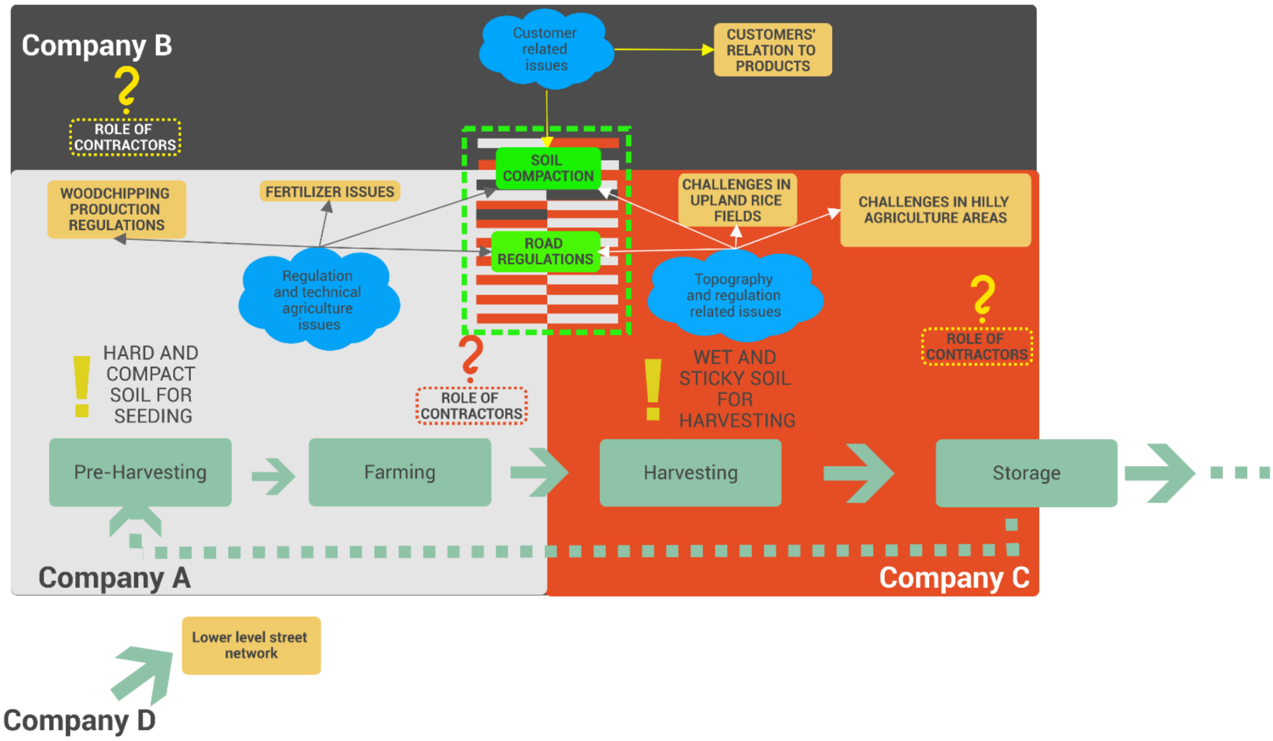


Figure 18. Overall supply chain at the first mile and locations of industrial partners

After the stages of data and information search and structuring and categorization of the challenges, an online survey that consisted of the challenges was created and shared with industrial and researcher partners in order for them to provide their opinions. The respondents were expected to rank each of the challenges that were extracted from the literature and other sources. The presented options were *crucial*, *important*, and *not important*. The option of *no information* was also given, considering that a respondent may not have any experience or knowledge regarding some of the challenges. Two of the four industrial partners responded to the online survey. At least one of the industrial partners ranked 65 challenges as either *important* or *crucial*. Company A validated (either *important* or *crucial*) 56 challenges, while Company B validated 33 challenges. In total, both companies marked

24 challenges as either *important* or *crucial*. These challenges are listed in *Table 8*. None of the challenges was ranked as *crucial* by both companies.

Table 8. Challenges that were ranked as either important or crucial by industrial partners

Cluster	**Challenge**
Natural Environment and Phenomena	Soil compaction
	Soil and water erosion issues
	Field traffic
	Extreme weather
	Climate change
	Decarbonization of machine operations
Regulations	Lack of defined policy to minimize soil compaction practices
	Issues related to governance and implementation of laws
Supply Chain and Logistics	Access to the latest production information
Infrastructure	Complex and poor road network and infrastructure
	Lack of technology use
	Lack of IoT adoption
	Inadequate drainage systems and road maintenance
	Road safety
	Accessibility to farmland and rural areas
	Inefficient tracking system
	Lack of maturity of technology for tracking farming and supply chain
Economics, Business and Finance	Cost in supply chain
	Increase in cost of fuel
	High input costs
	Lack of quality incentives
	Ignorance about concept of quality
Skill Set and Workforce	Lack of farm-related skills and need for modern agricultural practices
	Shortage of comprehensive professionals

The industrial partners were also asked to add challenges to the list in case they found them important but somehow were not mentioned or were missed in the literature.

The added challenges were the following:

- Trafficability on field and on low-level/unpaved roads
- Increased precipitation
- Shortened frozen period / Impact of snow and ground freezing
- Not enough time for adapting to fast-changing regulations in sustainability
- Lack of awareness, willingness, and skills regarding the use of the latest technology
- Lack of environment-friendly methods

3.2.2. Other expert interviews

As part of the LEVITOI project, interviews were conducted with seven experts in the field of agriculture logistics to discuss about the identified challenges from the literature, and the project was described to the interviewees. One of the researchers, Taha Karasu, already had plans to visit Turkey; thus, the interviewees were carefully selected from research and industrial perspectives. The interview program was initially scheduled between July 14 and 29, 2022. However, once the date approached, some scheduling changes were made. Therefore, the meetings were held between July 19 and August 11, 2022. Some of the interviews were conducted face-to-face, while others were held online. For the detailed program, please see Table 9.

Table 9. Information about interviewees in Turkey

Interview	Date	Title	Organization
Interview 1	July 19, 2022	CEO and Head of Roundtable	Dimes A.S., Turkish Industry and Business Association
Interview 2	July 19, 2022	Vice Chairperson of Executive Committee	International Transporters' Association of Turkey
Interview 3	July 21, 2022	Dr.	Maltepe University
Interview 4	July 22, 2022 July 22, 2022	Dr. Prof.	Maltepe University
Interview 5	July 28, 2022	Dean, Prof.	Sabanci University
Interview 6	August 11, 2022	Prof.	Bogazici University

Interviewee 1 is the CEO of one of the prominent fruit juice and nectar companies in Turkey. The company is highly export oriented. This interviewee is also the Head of Agriculture, Food and Services Roundtable of the Turkish Industry and Business Association (TUSIAD), which is responsible for 85% of the country's entire exports. The interviewee validated the majority of the challenges that were found in the literature. Interviewee 2 provided information prominently, not limited to the shipment route of agricultural produce when exported, particularly to Russia and the EU region. With the rest of the interviews, on the researcher side, the possibilities of collaboration on our research were discussed, and further interviews were planned. The contacts comprised key people in both Europe and the domestic market, who could provide more information about the field. For example, the contact from CEMA was able to provide more detailed information regarding the current level of knowledge about soil compaction and the agricultural machinery in CEMA.

Overall, the following conclusions can be drawn:

- Even though some of the challenges presented in this report are more specific to northern Europe, such as *shortened frozen period,* the challenges, especially those obtained from the literature, are global issues.
- Soil compaction has not been studied or not even heard of by our interviewees.
- The interviewees recognize the huge potential of reform in the fields of soil compaction in agriculture and first-mile logistics.
- Some organizations and contacts are willing to be included in the research endeavors and to support us with further information.
- Turkey has participated in major endeavors (from Europe and the UN) to improve agriculture logistics; thus, there is readiness to do more research in improving ASC.

3.3. Information value assessment

As shown in *Section 3.2.1*, not all challenges of first-mile logistics were directly related to the business of our industrial partners. The challenges were classified from this perspective in the aforementioned section. Due to the high number of challenges extracted from different kinds of resources, prioritization among the challenges would be needed as well, regardless of their connection to the interests of the industrial partners.

The challenges in our research pool were ranked, based on their dominance scores that were built around these two parameters:

(1) What is (are) the evidence level(s) of the source(s) of each challenge?
(2) What is the highest evidence level source of a challenge?

Based on the number of sources where a challenge was found and the evidence levels of the sources, the dominance scores of the challenges were determined. In line with the above parameters, a mathematical formulation was developed to determine the dominance scores of all identified challenges. Subsequently, they were ranked and classified.

(1) Evidence levels of sources

The evidence levels of sources have been prominently used in medical sciences to differentiate outcomes based on their generalizability (Stichler, 2010). The evidence levels of the sources were ranked, with the guidance of Stichler's (2010) work (see *Table 10*). The sources in the research pool were ranked based on a six-level evidence-ranking scale. Level 1 is the highest rank on the scale, while Level 6 is the lowest. Although there is no Level 1 in our research pool, Level 1 consists of meta-analyses or systematic reviews of highly evident sources, such as systematic reviews of Level 2 and Level 3 sources. Level 6 comprises stakeholder opinions and might be subjective.

Table 10. Evidence levels of individual sources in the research pool

Reference	Level	Reference	Level
Awan *et al.,* 2021	3	Commonwealth of Australia, 2016	5
Bannor and Kyire, 2021	3	Giovannucci *et al.,* 2012	4
Cagliano *et al.,* 2016	3	Department of Infrastructure and Regional Development, 2017	6
CEMA, 2022	4	Department of Environmental Food and Rural Affairs, UK, 2015	4
Chaerani *et al.,* 2022	3	Asian Development Bank *et al.,* 2016	4
Despoudi, 2021	4	European Commission, 2022	5
Gardas *et al.,* 2019	2	European Union, 2017	4
Han *et al.,* 2021	3	Angelucci *et al.,* 2013	5
Lamandé *et al.,* 2017	3	Fakava, 2012	5
Lingjuan *et al.,* 2018	3	Food and Agriculture Organization, 2017	4
Majluf-Manzur *et al.,* 2021	3	Government of India, 2019	5
Mirabelli and Solina, 2020	3	Xuezhen *et al.,* 2020	5
Naseer *et al.,* 2019	4	International Labour Organization, 2017	4
Obour *et al.,* 2017	3	Parfitt *et al.,* 2021	6
Onggo *et al.,* 2019	3	Iimi *et al.,* 2015	5
Patidar and Agrawal, 2020	3	Ludwig *et al.,* 2016	6
Patidar *et al.,* 2018	3	Kirubi, 2015	6
Porter and Reay, 2016	4	OECD/FAO, 2016	4
Raut *et al.,* 2019	2	Davidova and Thomson, 2014	4
Sadati *et al.,* 2021	6	Stolte *et al.,* 2016	4
Schjønning *et al.,* 2015	3	Tani Hub, 2020	6
Schjønning *et al.,* 2016	3	US Department of State, 2013	5
Schjønning *et al.,* 2017	3	US Department of Transportation, 2022	4
Soto-Silva *et al.,* 2017	3	European Commission *et al.,* 2021	3
Srivastava and Dashora, 2022	3	Bakst, 2016	5
Tang *et al.,* 2013	3	Easdown and Acedo, 2015	4
Tuure *et al.,* 2016	4	Food and Agriculture Organization, 2015	4
Violi *et al.,* 2020	3	Kurnik, 2019	4
Wen *et al.,* 2017	3	Ministry of Agriculture and Reforms, 2021	4
Xiao-yuan and Wei-hua, 2013	4	Van Dusen and Beyard, 2013	6
Yadav *et al.,* 2020	3	Petersen and Abrahamsen, 2021	3
Yang *et al.,* 2014	3	US Department of Agriculture, 2018	5
Frelih-Larsen *et al.,* 2018	4	World Bank, 2019	4
African Development Bank, 2010	4	Isbister *et al.,* 2013	5
Banjo *et al.,* 2012	4	Gray *et al.,* 2018	6
Berg *et al.,* 2016	4		

For each challenge, we seek the best-ranking source (RX_1) and take it as the base rank. Then for each source where a challenge is found in addition to the best-ranking source, the dominance level is improved. For instance, if challenge X is extracted from one Level-2 source and one Level-4 source, we take Level 2 (RX_1) as the base rank of challenge X. We then improve the ranking by the reverse of the second source where challenge X is found (RX_2). In this case, it is ¼ (0.25), and we revise the rank as follows:

"$DL_x = RX_1 - (1/RX_2)$"

$DL_x = 2 – 0.25$

$DL_x = 1.75$.

The developed formula that results in the dominance level of the challenge is as follows:

$DL_x = RX_1 - (\sum_{\mathrm{RXi}=2}^{n} \frac{1}{RXi})$

To cite a second example for challenge X that has 4 references with the evidence levels of [2, 3, 4, 4], the formula calculates the dominance level of challenge X as follows:

$DL_x = RX_1 - (\sum_{\mathrm{RXi}=2}^{n} \frac{1}{RXi})$

$DL_x = 2 - (\frac{1}{RX2} + \frac{1}{RX3} + \frac{1}{RX4})$

$DL_x = 2 - (\frac{1}{3} + \frac{1}{4} + \frac{1}{4})$

$DL_x = 2 – 0.83$

$DL_x = 1.17$

The same formula is applied to each challenge, and the overall ranking of the individual challenges can be found in *Table 11*.

Table 11. Dominance levels of challenges

Challenges	Number of References	Evidence Score
*Too long logistics / supply chain and excessive circulation links	**7**	**0.22**
*Heavy wastage throughout the supply chain	**5**	**0.67**
*Complex and poor road network and infrastructure	**4**	**1.25**
*Extreme weather	**4**	**1.25**
*Water scarcity and access to fresh water	**4**	**1.30**
*Soil compaction	**6**	**1.42**
*Cost in supply chain	**3**	**1.50**
*Long duration of infrastructure projects	**2**	**1.50**
*Challenges related to cold chain	**7**	**1.52**
*Large number of marketing channels and restricted access to markets of agri-produce	**2**	**1.75**
*Low price realization and information by farmers and rigging in market price settlement	**2**	**1.75**
*Increase in cost of fuel	**2**	**1.75**
*High cost of marketing and anti-competitive practices	**2**	**1.80**
*Lack of integration among farmers in production, transportation, and market	**5**	**1.83**
Limited agricultural market infrastructure	**1**	**2.00**
Lack of quality of produce	**1**	**2.00**
Seasonality	**1**	**2.00**
Usage of agri-land for bio-fuel production	**1**	**2.00**
Licensing hurdles	**1**	**2.00**
*Non-transparent processes	**5**	**2.08**
*Uncertainty in harvest yield and in market demand	**4**	**2.17**
*Lack of coordination between stages of supply chain	**4**	**2.30**
*Information sharing and decentralized information flow	**3**	**2.33**
*Aging workforce at farmgate / shortage and performance of labor	**3**	**2.50**
*Lack of blockchain adoption	**2**	**2.67**
*Subsoil compaction	**2**	**2.67**
*Lack of planning	**2**	**2.75**
*Perishable products	**2**	**2.75**
*Lack of trust among stakeholders	**2**	**2.75**
*Access to the latest production information	**2**	**2.75**
*Lack of proper land use regulations for agriculture	**2**	**2.80**
No direct procurement from farmers	**1**	**3.00**
Fragmented agricultural lands	**1**	**3.00**
Low efficiency in business sense	**1**	**3.00**
Lack of maturity of technology for tracking farming and supply chain processes	**1**	**3.00**
Lack of IoT adoption	**1**	**3.00**
Lack of hardware facilities	**1**	**3.00**
Field traffic	**1**	**3.00**
Tight connection to nature	**1**	**3.00**
Shortage of comprehensive professionals	**1**	**3.00**
Inefficiency in logistics	**1**	**3.00**
Numerous nodes of agricultural products	**1**	**3.00**
Disorganized decision making	**1**	**3.00**
Integration capability	**1**	**3.00**
*Climate change	**5**	**3.05**
*Disease and pest attacks	**4**	**3.30**
*Quality of fertilizers and pesticides	**4**	**3.38**
*Lack of defined policy to minimize soil compaction practices	**3**	**3.50**
*Lack of transportation infrastructure and facilities	**3**	**3.55**
*Lack of technology use	**3**	**3.58**
*Lack of storage infrastructure	**2**	**3.75**
*Lack of farm-related skills and need for modern agricultural practices / lack of educatior	**2**	**3.75**
*Traditional packaging / poor packaging practices and standards	**2**	**3.75**
*Exploitation of intermediaries and lack of competition among them	**2**	**3.75**
*High taxation on agriculture-related products	**2**	**3.80**
*Accessibility to farmlands and rural areas	**2**	**3.80**

*Access to credit	**2**	**3.83**
Hard to manage fruit production	**1**	**4.00**
Road safety	**1**	**4.00**
Low level of processing	**1**	**4.00**
Outdated irrigation approaches	**1**	**4.00**
High input costs	**1**	**4.00**
No marketing investment	**1**	**4.00**
Lack of understanding about changing market requirements	**1**	**4.00**
Ignorance about concept of quality	**1**	**4.00**
Lack of quality incentives in general, in packaging, and in proper grading by size	**1**	**4.00**
Increased freight trucking prices	**1**	**4.00**
High cost of telecommunication	**1**	**4.00**
Access to machinery and equipment	**1**	**4.00**
Inadequate drainage systems and road maintenance	**1**	**4.00**
Decarbonization of machine operations	**1**	**4.00**
Lack of environmentally friendly practices	**1**	**4.00**
Deteriorating soil fertility	**1**	**4.00**
Issues related to governance and implementation of laws	**1**	**4.00**
Lack of understanding of the changing regulations	**1**	**4.00**
Health issues of workers; weather conditions, exposure to chemicals	**1**	**4.00**
Human rights and child labor issues	**1**	**4.00**
Lack of packaging facilities	**1**	**4.00**
Poor handling	**1**	**4.00**
Lack of adequate technical support	**1**	**4.00**
Maintenance of documents for certification	**1**	**4.00**
Lack of proper marketing	**2**	**4.83**
Poor post-harvest management and post-harvest management infrastructure	**2**	**4.83**
Fertilizer cost	**1**	**5.00**
Lack of ripening facilities	**1**	**5.00**
Wind erosion	**1**	**5.00**
Soil and water erosion issues	**1**	**5.00**
Leaching issues	**1**	**5.00**
Uneven distribution of storage facilities	**1**	**5.00**
Traditional management	**1**	**6.00**
Inefficient tracking system	**1**	**6.00**

*The challenges that actualize the constraints

The median of the dominance level of the research pool is 3.30, and the standard deviation is 1.16. The value of “M+(A/2)” is defined as the breakpoint that defines “dominant” and “non-dominant” challenges. The value is 3.88.

Two constraints are set to define dominant challenges in the research pool. The first constraint is that the dominance score should be lower than 3.88. The second constraint is that a challenge should have at least two references.

3.4. Quality function deployment (QFD)

QFD is a system/tool that was developed in Japan in the 1960s. This flexible and comprehensive decision-making tool is used in product and/or service development, brand marketing, and product management. QFD is a structured approach that was originally used to define customer needs and requirements and to translate them into specific plans in product management to meet the customer requirements.

The house of quality matrix is one of the most recognized and widely used form of applying QFD. In general, the house of quality includes six major components, as follows:

1. customer requirements (in our case, first-mile challenges in agriculture logistics)
2. technical specifications
3. planning matrix
4. interrelationship matrix
5. technical correlation matrix
6. technical priorities

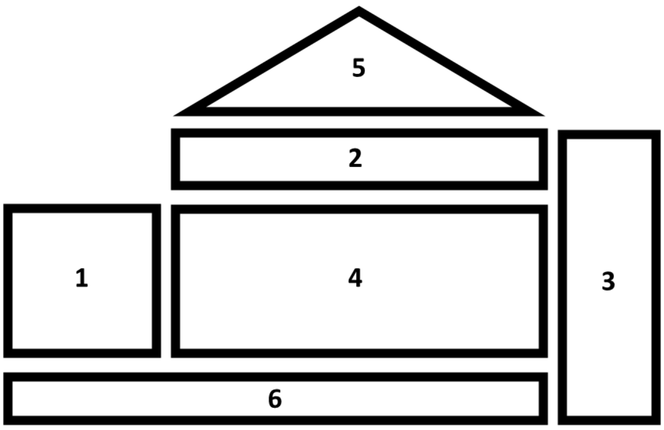


Figure 19. House of quality

1. First-mile challenges in agriculture logistics

Previously, 93 challenges were found from both scientific and gray literature and were presented in a workshop that was held in June 2022 for the industrial partners of the LEVITOI project. The industrial partners ranked each challenge as *crucial, important,* or *not important*. The challenges that were ranked as either *crucial* or *important* were included in the QFD analysis. As expected, the partners ranked the challenges differently; thus, the partners had different lists of challenges, although these largely intersected. In addition to the 93 identified challenges from the literature, the partners were asked to add challenges to the list if these were not found in the literature. The challenge list has three columns, namely first level, second level, and third level, indicating our first categorization of the challenges.

2. *Prospective action categories*

Prospective actions are categorized into two types: prospective actions in product features and prospective actions in market strategy. Although QFD is a tool that is mostly related to product/service development, we inferred that not all challenges that were ranked as important or crucial could be tackled with merely product development endeavors. Thus, we have added another category that relates actions to market strategy, which is more related to stakeholder management. Once a challenge is identified, there might be two approaches. An organization can either adapt to the challenge and alter its product development strategy, or support the industry to tackle the challenge at its source, often in collaboration with other stakeholders. The possibilities may increase, yet we have identified four stakeholder groups: regulators, other equipment and machine producers, agricultural producers, and other stakeholders (e.g., pesticide and fertilizer providers, consultants, etc.). A combination of product development actions and market strategy actions may be needed to tackle certain challenges. Additionally, the industrial partners have different products and thus different product features. All in all, each industrial partner is advised to work on a different house of quality sheet.

3. *Planning matrix*

The planning matrix has four columns: dominance level in the literature, previous opinion in the workshop, relationship with competitive advantage, and prioritization of challenges. The dominance level category reflects the dominance score of each listed challenge. The column bears an informative feature for industrial partners to show how a certain challenge is dominant in the literature (for more details, see *Section 3.3*). The challenges are ranked as *very strong, strong, medium,* or *weak*. As mentioned, the partners' opinions about individual challenges were previously solicited in the workshop; thus, their previous rankings are also noted to facilitate the process of prioritizing the challenges. The industrial partners are not NGOs; thus, they have concerns about profitability and increasing their competitive advantage. The third column gives them the opportunity to rank how a certain challenge relates to their competitive advantage. A threefold ranking is applied in this column: *high, medium,* or *low*. The last column inquires how the partner ranks the challenge overall, considering dominance, in relation to competitive advantage and their previous opinion. A threefold ranking is applied in this column as well: *first, second,* or *third* category.

4. Interrelationship matrix

With the identified challenges, the partners can begin to formulate a strategy to improve a product or develop a market strategy. Considering the organization's strengths and weaknesses, the breakdown of the product features, and the dominant challenges and their relation to competitive advantage, the partners are asked to contemplate which challenges are related to which product feature or market strategy. Is it worth taking action(s), are we aiming to surpass the competition or be equal in competition, or should we leave this aspect unchanged?

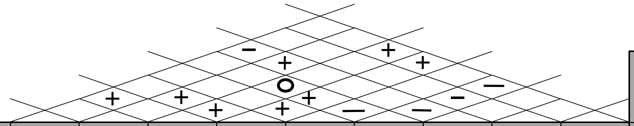
5. Technical correlations matrix

The technical correlations matrix is the roof of our house of quality and provides support in developing relationships between challenges and prospective actions. It shows which actions positively affect each other (+), which actions are in a tradeoff relationship (-), and which actions are related, not necessarily negatively or positively, but certainly, they should be handled together (O).

6. Technical priorities

Actions may differ in their degrees of difficulty, yet organizations have varying strength levels in different actions. Some actions may be difficult to apply for some organizations, while for others, these may be easy to apply, depending on how much resources they have—human resources, time, and so on. After all, the organizations are also asked to rank the difficulty of applying the actions in real life. A five-tier ranking is applied in this section, namely *very high, high, medium, low,* or *very low*.

Examples of the house of quality for Company A and Company B are shown in *Figure 20* and *Figure 21*, respectively.



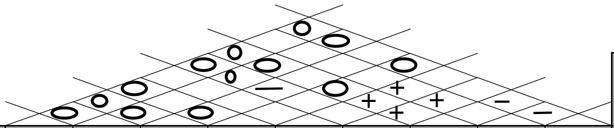
CHALLENGES

PROSPECTIVE MARKET STRATEGY ACTIONS

PLANNING MATRIX

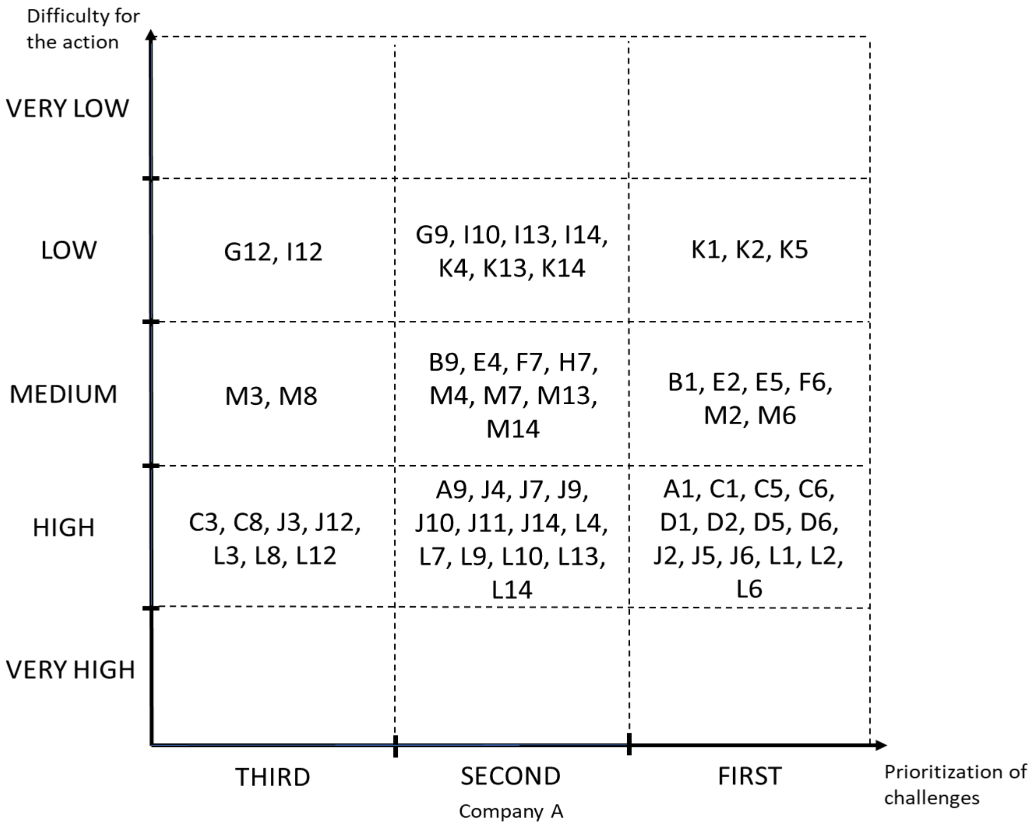
FIRST LAYER OF CHALLENGES	SECOND LAYER OF CHALLENGES	THIRD LAYER OF CHALLENGES / PROSPECTIVE ACTIONS IN PRODUCT FEATURES	Codes	A Weight of the vehicle	B Weight distribution	C Multipurpose vehicle (combined)	D Efficiency of the vehicle	E Design for sustainability	F Design for cost	G Design for safety	H Design for quality	I Optimize the technology	J Influence the regulaters	K Cooperate with other machine / equipment providers- CEMA /MTK	L Cooporate with the end users / farmer unions	M Cooperate with other stakeholders than farmers and machine / equipment providers	DOMINANCE LEVEL IN THE LITERATURE	PREVIOUS OPINION IN THE WORKSHOP	RELATIONSHIP WITH COMPETITIVE ADVANTAGE	PRIORITIZATION OF CHALLENGES
NATURAL ENVIRONMENT AND PHENOMENA	SOIL COMPACTION	Compaction of surface soil	1	A1	B1	C1	D1							K1	L1		VERY STRONG	IMPORTANT	HIGH	FIRST
		Soil and water erosion issues															WEAK	CRUCIAL		
	EXTREME WEATHER	Extreme weather	2				D2	E2					J2	K2	L2	M2	VERY STRONG	IMPORTANT	HIGH	FIRST
		Climate change															MEDIUM	CRUCIAL		
	OTHERS	Disease and pest attack	3			C3							J3		L3	M3	MEDIUM	IMPORTANT	LOW	THIRD
		Soil fertility is deteriorating	4					E4					J4	K4	L4	M4	WEAK	CRUCIAL	MEDIUM	SECOND
		De-carbonisation of machine operations.	5			C5	D5	E5					J5	K5			WEAK	IMPORTANT	HIGH	FIRST
ECONOMICS, BUSINESS AND FINANCE	TRANSPORT ECONOMICS	Cost in supply chain	6			C6	D6		F6				J6		L6	M6	VERY STRONG	CRUCIAL	MEDIUM	FIRST
		Increase in cost of fuel															STRONG	CRUCIAL		
	INVESTMENT	High input costs															WEAK	IMPORTANT		
		Access to credit															MEDIUM	IMPORTANT		
	OTHERS	High Taxation on agriculture related products															MEDIUM	IMPORTANT		
	QUALITY	Quality of fertilizers and pesticides	7						F7		H7		J7		L7	M7	MEDIUM	IMPORTANT	MEDIUM	SECOND
		Lack of quality incentives (in general, in packaging and proper grading by size)															WEAK	IMPORTANT		
		Ignorance on concept of quality															WEAK	IMPORTANT		
	BUSINESS MODELS	Lack of planning	8			C8									L8	M8	MEDIUM	CRUCIAL	LOW	THIRD
INFRASTRUCTURE	PHISICAL	Complex and poor road network and infrastructure	9	A9	B9					G9			J9		L9		VERY STRONG	IMPORTANT	MEDIUM	SECOND
		Accessibility to farmland and rural areas															MEDIUM	IMPORTANT		
		Inadequate drainage systems and road maintenance															WEAK	IMPORTANT		
		Road Safety															WEAK	IMPORTANT		
	DIGITAL	Lack of technology use	10									I10	J10		L10		MEDIUM	IMPORTANT	HIGH	SECOND
		Inefficient tracking system															WEAK	IMPORTANT		
REGULATIONS		Lack of defined policy to minimize soil compaction practices	11										J11				MEDIUM	IMPORTANT	MEDIUM	SECOND
		Issues related to governance and implementation of laws															WEAK	IMPORTANT		
		Lack of understanding of the changing regulations															WEAK	IMPORTANT		
SKILL SET AND WORKFORCE		Ageing workforce at farmgate / shortage and performance of labor	12							G12		I12	J12		L12		STRONG	IMPORTANT	MEDIUM	THIRD
		Lack of farm-related skills and need for modern agricultural practices / lack of education															MEDIUM	IMPORTANT		
SUPPLY CHAIN MANAGEMENT AND LOGISTICS	SUPPLY CHAIN	Non transparent processes	13									I13		K13	L13	M13	STRONG	CRUCIAL	MEDIUM	SECOND
		Lack of integration between farmers in production, transportation and market															STRONG	IMPORTANT		
		Lack of coordination between stages of supply chain															STRONG	IMPORTANT		
		Exploitation of middlemen and lack of middlemen competition															MEDIUM	CRUCIAL		
		Access to the latest production information															MEDIUM	IMPORTANT		
	LOGISTICS	Lack of transportation infrastructure and facilities	14									I14	J14	K14	L14	M14	MEDIUM	IMPORTANT	MEDIUM	SECOND
		Too long logistics / supply chain and excessive circulation links															VERY STRONG	CRUCIAL		
DIFFICULTY TO IMPROVE THE PRODUCT FEATURE OR MARKET STRATEGY				HIGH	MEDIUM	HIGH	HIGH	MEDIUM	MEDIUM	LOW	MEDIUM	LOW	HIGH	LOW	HIGH	MEDIUM				

Figure 20. House of quality for Company A



CHALLENGES: FIRST LAYER OF CHALLENGES	SECOND LAYER OF CHALLENGES	THIRD LAYER OF CHALLENGES / PROSPECTIVE ACTIONS IN PRODUCT FEATURES	Codes	A Tyre design	B Tyre material	C Tyre weight	D Tyre structure	E Easy adjustable tyre pressure	F More loading capacity of tyres	G Suitable tyres for different terrain and weather	H Optimize the technology	I Design for cost	J Influence the regulaters	K Cooperate with other machine / equipment providers- CEMA /MTK	L Cooperate with the end users / farmer unions	M Cooperate with other stakeholders than farmers and machine / equipment providers	DOMINANCE LEVEL IN THE LITERATURE	PREVIOUS OPINION IN THE WORKSHOP	RELATIOPNSHIP WITH THE COMPETITIVE ADVANTAGE	PRIORITIZATION OF CHALLENGES
													PROSPECTIVE MARKET STRATEGY ACTIONS				PLANNING MATRIX			
NATURAL ENVIRONMENT AND PHENOMENA	SOIL COMPACTION	Compaction on surface soil	1	A1	B1	C1		E1	F1	G1				K1	L1		VERY STRONG	CRUCIAL	HIGH	FIRST
		Sub-soil compaction															STRONG	CRUCIAL		
		Soil and water erosion issues															WEAK	IMPORTANT		
	EXTREME WEATHER	Extreme weather	2	A2	B2	C2	D2	E2	F2	G2			J2	K2	L2	M2	VERY STRONG	IMPORTANT	HIGH	FIRST
		Climate change															MEDIUM	IMPORTANT		
		Increased precipitation															WEAK	IMPORTANT		
		Shortened frozen period															WEAK	IMPORTANT		
	OTHERS	De-carbonisation of machine operations.	3								H3		J3	K3			WEAK	IMPORTANT	MEDIUM	SECOND
		Seasonality	4				D4							K4	L4		WEAK	IMPORTANT	MEDIUM	SECOND
ECONOMICS, BUSINESS AND FINANCE	INVESTMENT	High input costs	5	A5								I5	J5		L5	M5	WEAK	IMPORTANT	HIGH	FIRST
	TRANSPORT ECONOMICS	Cost in supply chain															VERY STRONG	IMPORTANT		
		Increase in cost of fuel															STRONG	IMPORTANT		
	QUALITY	Lack of quality incentives (in general, in packaging and proper grading by size)	6								H6	I6	J6			M6	WEAK	IMPORTANT	MEDIUM	SECOND
		Ignorance on concept of quality															WEAK	IMPORTANT		
INFRASTRUCTURE	PHISICAL	Complex and poor road network and infrastructure	7	A7			D7	E7		G7			J7		L7		VERY STRONG	CRUCIAL	HIGH	FIRST
		Accessibility to farmland and rural areas															MEDIUM	IMPORTANT		
		Inadequate drainage systems and road maintenance															WEAK	CRUCIAL		
		Road Safety															WEAK	IMPORTANT		
		Traficability on field and on lower level / unpaved roads															WEAK	CRUCIAL		
	DIGITAL	Lack of blockchain adoption	8								H8		J8	K8	L8	M8	STRONG	IMPORTANT	MEDIUM	SECOND
		Lack of technology use															MEDIUM	IMPORTANT		
		Inefficient tracking system															WEAK	IMPORTANT		
REGULATIONS		Lack of defined policy to minimize soil compaction practices	9										J9	K9	L9		MEDIUM	IMPORTANT	HIGH	SECOND
		Lack of proper land use regulations for agriculture															MEDIUM	IMPORTANT		
		Issues related to governance and implementation of laws															WEAK	IMPORTANT		
SKILL SET AND WORKFORCE		Lack of farm-related skills and need for modern agricultural practices / lack of education	10		B10						H10		J10	K10	L10	M10	MEDIUM	IMPORTANT	LOW	SECOND
		Lack of environmental and soil friendly methods															WEAK	IMPORTANT		
		Lack of eagerness and education on adoption of latest technology															WEAK	IMPORTANT		
SUPPLY CHAIN MANAGEMENT AND LOGISTICS	SUPPLY CHAIN	Information sharing and decentralized information flow	11								H11				L11		STRONG	IMPORTANT	LOW	THIRD
		Access to the latest production information															MEDIUM	IMPORTANT		
DIFFICULTY TO IMPROVE THE PRODUCT FEATURE OR MARKET STRATEGY				HIGH	MEDIUM	HIGH	MEDIUM	LOW	MEDIUM	HIGH	MEDIUM	HIGH	HIGH	LOW	HIGH	MEDIUM				

Figure 21. House of quality for Company B



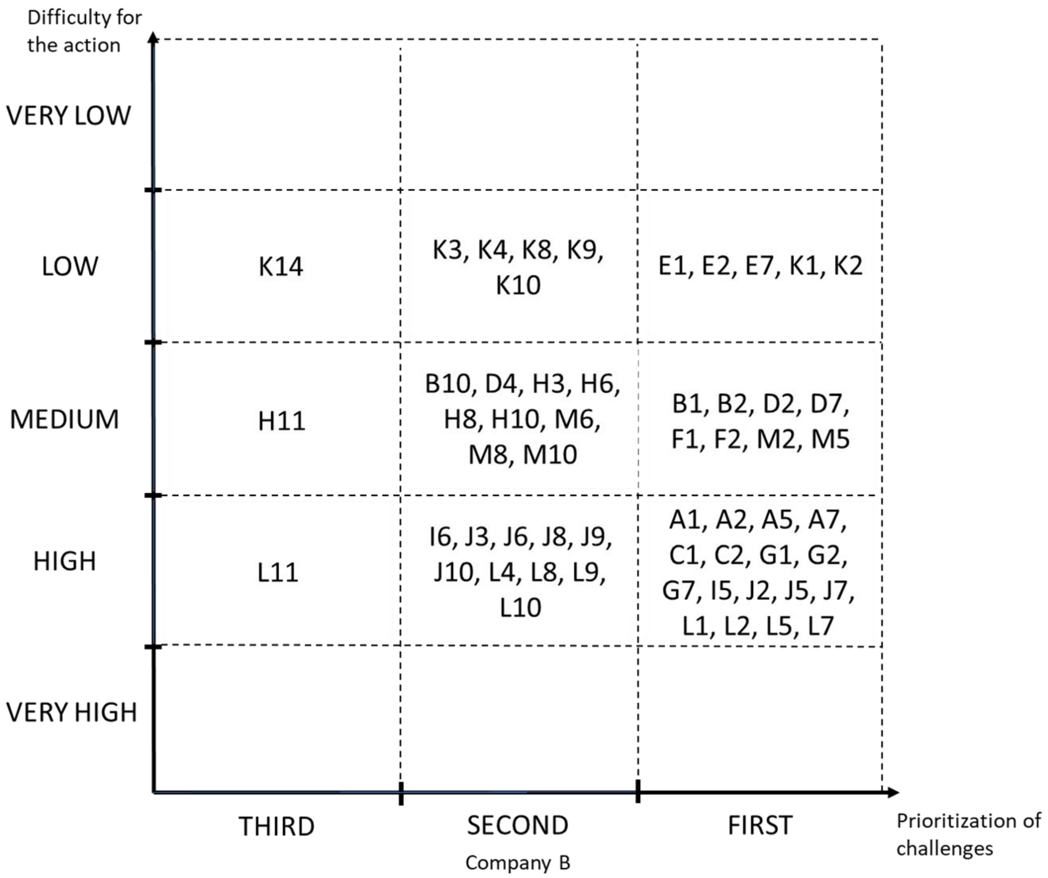


Figure 22. Summary diagram of house of quality examples for Company A and Company B

The matrices of prioritization and difficulty for action to improve a product feature or a market strategy are presented in *Figure 20* and *Figure 21* at the company level. The codes correspond to certain actions to tackle certain challenges. For instance, H3 corresponds to a prospective improvement in the *optimization of technology* of a product to tackle *decarbonization of machine operations* for Company B *(Figure 21)*.

The more the actions are located on the top right of the matrix, as shown in *Figure 22*, the more the strength of suggestion increases to take the action for the industrial partners.

In the case of Company A, the following actions are strongly suggested:

K1: *"Cooperate with other machine / equipment providers"* for *"soil compaction"*

K2: *"Cooperate with other machine / equipment providers"* for *"extreme weather"*

K5: *"Cooperate with other machine / equipment providers"* for *"decarbonization of machines "*

It is suggested that the actions that are located at the bottom left of the matrix *(Figure 22)* be avoided initially, since they take much effort for less prioritized challenges. Such actions are listed below:

C3: *"Multipurpose vehicle (combined)"* for *"disease and pest attacks"*

C8: *"Multipurpose vehicle (combined)"* for *"lack of planning"*

J3: *"Influence the regulators"* for *"disease and pest attacks"*

J12: *"Influence the regulators"* for *"skill set and workforce"*

L3: *"Cooperate with the end users / farmer unions"* for *"disease and pest attacks"*

L8: *"Cooperate with end users / farmer unions"* for *"lack of planning"*

L12: *"Cooperate with end users / farmer unions"* for *"skill set and workforce"*

In the case of Company B, the following actions are strongly suggested:

E1: *"Easily adjustable tire pressure"* for *"soil compaction"*

E2: *"Easily adjustable tire pressure"* for *"extreme weather"*

E7: *"Easily adjustable tire pressure"* for *"physical infrastructure"*

K1: *"Cooperate with other machine / equipment providers"* for *"soil compaction"*

K2: *"Cooperate with other machine / equipment providers"* for *"extreme weather"*

It is suggested that the action that is located at the bottom left of the matrix *(Figure 22)* be avoided initially, since it takes much effort for less prioritized challenges. Such an action is stated below:

L11: *"Cooperate with the end users / farmer unions"* for *"supply chain-related challenges"*

The actions that are located around the centre should be pondered carefully, with consideration for the organization's long-term goals, mission, and vision. Tools such as SWOT and derivatives can also be useful for more contemplation about these actions.

Another factor to be taken into account when deciding whether or not to perform the action involves technical specifications' co-relations. For instance, if a company decides to take a particular action to tackle a certain challenge, the other product features that become affected by this change are shown on the roof of the house of quality.

Challenges of *soil compaction, extreme weather,* and cost-related challenges, such as *high input cost, cost in SC,* and *increase in cost of fuel,* are marked as first priority for both studied companies. Thus, more studies and greater focus are needed to elaborate on these challenges and jointly support the solution process. Particularly, we could not find enough data for the challenge of soil compaction in the context of first-mile logistics. Nevertheless, subsequent WPs of the LEVITOI project endeavor to study the phenomena through in-situ tests, laboratory tests, and simulations. The need for such efforts is once more justified with the outcome of this report. The QFD indicates that cost-efficient agricultural machinery and equipment that cause as little as possible soil compaction under varied extreme weather conditions are primarily needed in the industry.

4. Body of knowledge regarding simulation and testing in soil–machine interaction on sensitive grounds

4.1. Soil consolidation versus soil compaction and their effects

From the geotechnical perspective, soil compaction can have positive or negative impacts on the ground, depending on the application. Basically, soil can be compacted due to the force or loading and naturally, due to the consolidation process. Consolidation is a process that differs from compaction, despite their similarities. In consolidation, the soil is being compacted when the water is flowing away from the voids of the soil matrix, whereas in compaction, the air is exiting from the voids (Craig, 2004). Consolidation plays a significant role in soft soils (e.g., clay), but it is time-dependent (takes several years). Compaction can affect all types of soils, and the process is quick. The loading type is also different; in consolidation, it is a static and long-term (e.g., foundation) type, whereas in compaction, it is a dynamic and short-term type. The similarities are that the shear strength increases, while the void ratio, compressibility, and permeability decrease (Craig, 2004). Overall, the result is the same; the soil settles and is compacted.

Compaction is mostly used because it increases the bearing capacity of the soil. In turn, from the agricultural perspective, compaction negatively affects soil function by decreasing productivity (e.g., Horn *et al.,* 1995; Schjønning *et al.,* 2012; De Pue, 2019). The negative effects mainly concern changes in the water balance. Normally, compaction decreases water conductivity (k-value) in the soil and causes changes to pore systems (Horn *et al.,* 1995). This makes it harder for water to flow into the soil and prevents plants from receiving water, air, and nutrients. According to Alaoui and Diserens (2018) and Alaoui *et al.* (2011), soil compaction leads to increased erosion by increasing runoff and flood risks, as well as decreased drought resilience. Additionally, the functionality of the drainage systems deteriorates, and it causes waterlogging. Therefore, soil compaction is pointed out as the most significant threat to soil quality. In agriculture and subsoil compaction, the stress through compaction is caused mainly by the weight of heavy machinery used in field operations. Modern vehicles have become heavier and larger than previously, and vertical stresses on the subsoil are therefore greater. In the 1980s, wheel loads were 40–50 KN, but currently, they have reached 90–120 KN (Keller, 2004; Schjønning *et al.,* 2016). Conventional plowing techniques cannot restore existing deformations. Overall, soil compaction has consequences that have negative impacts on the chemical, physical, and biological functions of the soil in terms of production capacity.

4.2. Risk assessment of soil and different testing methods

Soil compaction affects stress transmission and soil deformation in multiple ways. Soil is a heterogeneous matrix, and it makes modeling complex. The deformations can be classified as elastic or plastic, based on the classical continuum theory of soil mechanics. According to Schjønning and Lamandé (2018, p. 116), "Most risk assessments for agricultural soils are based on a comparison of the vertical stress component with some estimate of soil strength deriving from uniaxial, confined compression tests." Alexandrou *et al.* (2002) mentions three essential soil properties that should be known: a) the stress-strain (stress-sinkage) characteristics of soil, b) soil strength during the initial stage of loading, and c) the mode of soil deformation within the soil profile for a given loading situation. Therefore, the most common soil property in soil compaction research is precompression stress (σ_{pc}). This mechanical soil property can be investigated in the laboratory (e.g., with the uniaxial, confined compression test or oedometer test). The mechanical precompression stress indicates the stress history of the examined soil and its load-carrying capacity. Another important value to measure and monitor is the saturated hydraulic conductivity k_s-value. There is an indication of a relation between hydraulic conductivity and soil quality. The challenge arises from the measurements of these parameters. For example, the measurement of water conductivity depends on a number of factors, ranging from sample processing, sample quality, and the used method to the analysis of the results, to mention a few. Currently, the methods are not standardized. Other factors of interest are soil particle size distribution (mainly clay content), matric potential, bulk density, and soil organic matter (OM) content. Overall, the following laboratory tests are mainly used:

- dry unit weight tests, Standard and Modified Proctor test (*Figure 24)*
- consolidation (e.g., uniaxial compression or oedometer test; ≥ 24-h loads)
- penetration (e.g., California Bearing Ratio [CBR] test)
- triaxial test
- water retention curve, pF
- water conductivity (*Figure 24*)
- basic soil characterization, such as particle size distribution

The following are in situ tests:

- Standard Penetration Test (SPT)
- Cone Penetration Test (CPT)
- modern electric piezocone penetrometer (CPTU)

- In situ hydraulic conductivity tests (e.g., double-ring infiltrometer or Guelph infiltrometer; *Figures 23, 24,* and *25*)

Most of the above-mentioned tests are typical geotechnical measurements that can be ordered from consultants. For example, in Finland, they are carried out in universities such as University of Oulu, Tampere University of Technology, and Aalto University.

Figure 23. Left: Hydraulic conductivity or permeability can be measured using several methods in the laboratory. The figure shows flexible-wall permeability cells. Right: The Proctor experiment can be used to find out the parameters associated with the compaction of the material.

Figure 24. Double-ring infiltrometer, mostly used for the in situ hydraulic conductivity test method (Anne Tuomela)

Figure 25. The Guelph infiltrometer can measure a lower hydraulic conductivity level (compared with the double-ring infiltrometer) and can be used in deeper soil (Anne Tuomela)

The risk assessment evaluation of soil compaction can be made in two steps. In the first step, the stress transmission in a soil profile is approximated. The evaluater pays attention to the soil profile and properties, as well as the wheel loads, load distribution, and tire contact area (De Pue, 2019). When modeling the compaction, several methods and software are available. The finite element method (FEM) has traditionally been used (Poodt *et al.,* 2003), but recent studies have switched to the discrete element method (DEM) (De Pue, 2019). Some commercial programs are available, such as Terranimo® (Stettler *et al.,* 2014) or SOCOMO (Van Den Akker, 2004), to help farmers and other stakeholders estimate the risk of soil compaction under agricultural vehicles. A newer option involves the use of visual soil evaluation methods, called the Visual Evaluation of Soil Structure (VESS) for subsoil (SubVess) or the Visual Soil Assessment (VSA) (Ball *et al.,* 2017).

Sensor techniques can be used in the field, and currently, real online monitoring systems offer interesting new possibilities. Hemmat and Adamchuk (2008) summarized sensor system possibilities in agriculture. Geophysical tools constitute one option; for example, electrical resistivity tomography (ERT) is popular for near-surface characterization (Oyeyemi *et al.,* 2017). The use of drones serves as a cost-efficient way to map and manage fields, among others. As the technology evolves, these are becoming more practical tools for farmers (Bedord, 2020). Drones have many useful sensor techniques available, such as red green blue (RGB), near infrared (NIR), multispectral, thermal, and light detection and ranging (LIDAR). Together with satellite data, drones have many potential applications.

However, researchers offer some practical rules for farmers to avoid unwanted compaction. Schjønning *et al.* (2012) recommend the "50-50" rule, where water contents near the field capacity, traffic on agricultural soil should not exert vertical stresses above 50 KPa in a depth of >50 cm. They also propose that farmers use the simple "8-8" rule in evaluating the usability of moist fields under traffic load, stated as follows: "The depth of the 50-kPa stress isobar increases by 8 cm for each additional tonne increase in wheel load and by 8 cm for each doubling of the tire inflation pressure" (Schjønning *et al.,* 2012, p. 390).

4.3. Studies of strain in road structures under stress in Finland in the 2000s

In the 21st century, studies related to the behavior of the structures of the Finnish roadways have focused on examining the sustainability of roads as the dimensions and overall masses of heavy traffic transport combinations continuously increase in line with industry needs.

It is claimed that increasing masses and dimensions of vehicle combinations would have the greatest negative impacts on sparsely populated areas and low-traffic roads, which include thin-paved and structured roads and gravel roads. The aforementioned roads in Finland are sometimes characterized by poor load-bearing subsoil and the lack of planning of the road structure ("unbuilt roads"), based on the soil materials of the structural layers acquired in the immediate vicinity of the road.

The negative effects of increasing masses and dimensions of vehicle combinations on road resistance are considered to contribute to the volume of water on road structures in Finnish climatic conditions in different seasons, the most critical of which are autumn and spring. As a result, seep and spring skeletal breakage may occur on roads on lower road networks. During the worst time, the structure of parts of the road cannot withstand heavy traffic, and weight restrictions have to be imposed on the road parts, which therefore prevent the road from being used in heavy traffic and impose considerable costs, for example, on the Finnish industry, especially forestry. The costs are incurred as a result of the complete disincentive of retrieving the felled raw material wood along the roads or the additional costs of circumventing weight-limited roads.

4.3.1. ROADEX and high-capacity transportation (HCT)-related research projects

In Finland, Tampere University of Technology (TUT) and Roadscanners have participated in ROADEX research projects that have studied the roadways of sparsely populated areas in Finland, Sweden, Norway, Scotland, Ireland, and Iceland since 2003 (Varin and Saarenketo, 2014; Johansson *et al.,* 2017; Munro and MacCulloch, 2008; Roads on Peat, ROADEX e-learning material; Survey and Monitoring Techniques; Roads on Peat, Investigations and surveys; Permanent deformation).

Another body of research conducted in Finland consists of projects that have investigated the behavior of road structures under stress, where TUT and/or the University of Oulu have been responsible for the research. Most of the research projects have aimed at examining the effects of the introduction and expansion of the use of high-capacity transportation (HCT) vehicle combinations on Finnish roadworks (thick-paved and thin-paved roads, gravel roads, and forest roads). In HCT-related projects, the references to HCT vehicles have been trucks under current restrictions, whose impacts on gravel roads and forest roads have also been measured as part of these projects. *Figure 26* shows the major completed and ongoing HCT-related projects in the timeline under study (Vuorimies *et al.,* 2009, 2018, 2019a, 2019b; Kolisoja *et al.,* 2015; Kalliainen and Kolisoja, 2015; Pekkala and Haataja, 2014, 2018, 2019; Pirjo and Asko, 2020; TTY, 2022).

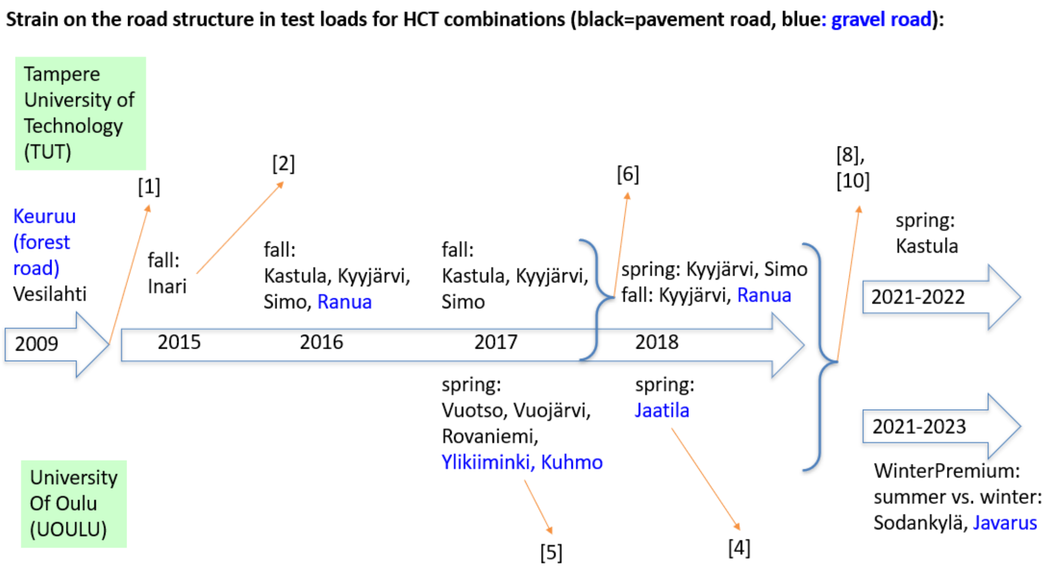
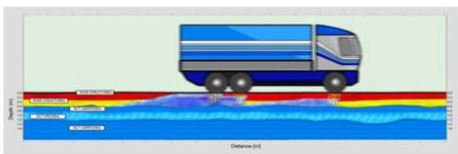


Figure 26. High-capacity transportation (HCT)-related projects in the timeline under study

4.3.2. Phenomena

Completed studies

The conducted studies have focused on the phenomena that cause stress in the road structures. The most significant are traffic loads, environmental load, and especially their combined effects. Regarding environmental load, during different seasons, the presence of water under different conditions and in different quantities in road structures, as well as the effects of this occurrence on the behavior of road structures, are examined. One example is a decrease in the bearing capacity of the road during spring thaw. Traffic stresses are caused by heavy traffic, in other words, the effects of the axle structure and amount, tire types, and tire pressures of vehicle combinations on the road's load-bearing capacity. Vehicle combinations can currently have a maximum of 9 axles and a weight of 76 tons. In the conducted studies, the largest HCT combinations have had 13 axles and a total mass of 104 tons. For the studies on gravel roads, the largest vehicle combinations have had 10 axles and weighed 84 tons. Simply stated, the stress caused by the total mass of vehicles is transferred through the surface area in contact with the road surface, that is, from the axles and tires beneath the vehicles to the road structures. The issues to be examined in the contact area include the number of axles and the total mass of the vehicle combination, in addition to the type of tire (super single versus double wheel), tire pressure (e.g., Tire Pressure Control System [TPCS] / Central Tire Inflation System [CTIS]), and axle structure (extra axle between the current axle in the ATWheels trailer; see *Figure 27*). One example of the combined effect of traffic and environmental load is the cumulative stress on road structures caused by several consecutive axles on thin-paved roads and gravel roads. Under certain conditions, this causes a pumping movement, which raises the water in the road structures toward the road surface (see *Figure 28*).



Figures 27, 28, and 29:
Figure 27 (left). ATWheels system (Pekkala and Haataja, 2019)
Figure 28 (middle). Pumping effect on road structures (water flowing toward road surface) (Vuorimies, 2019b)
Figure 29 (right). Central Tire Inflation System (CTIS) (Vuorimies *et al.,* 2009)

Ongoing studies

The Winter Premium study (Pekkala and Niskanen, 2014), led by the University of Oulu and the Finnish Meteorological Institute, focuses on the potential of lifting heavy vehicle weights in winter time when the freezing front depth makes safety lifting possible. The detailed survey areas are as follows:

- Investigating the impact of climatic conditions on roads' load bearing capacity and more real-time use of weight limitations, enabling more efficient use of roadways during spring thaw weakening
- Collecting and utilizing crowdsourced data on road conditions for weight limitations
- Examining the impact of freezing front depth on roads' load bearing capacity
- Developing weather prediction models to better reflect local conditions

Under suitable conditions, the road structure will be pressed down under the tires; eventually, rutting will form according to the driving lines. Another ongoing HCT-related study is led by TUT (TTY, 2022) and is focused on the theory that it could even be possible to at least slow down road rutting (or even "mold" the formed rutting into something shallower) by controlled varying of heavy vehicle driving lines.

The survey key points are listed as follows:

Research objects
- Stress (combination of traffic and environmental loads) effect on road structure
- Bearing capacity of different road types and structures under stress

Road attributes (structure, layers, materials, topography)
- Thick-structure pavement road
- Thin-structure pavement road
- Unpaved road ("built" and "unbuilt" gravel road, forest road)

Vehicle attributes = traffic load
- Total weight (76 t–103 t)
- Total number of axles (7–13)
- Total tire surface (individual tires)
- Tire pressure (CTIS)
- Axle structure (additional axles/tires = ATWheels)
- Driving lines

Environmental attributes = environmental load
- Amount and form of water
- Other weather conditions (e.g., air and road structure temperature)

4.3.3. Measurement methods and techniques

The things to be measured can be divided into traffic load effects, conditional factors, and traffic and driving manner factor measurements (Savolainen *et al.,* 2001). Some examples and alternative measurement methods used in HCT projects are listed in *Table 12* (Vuorimies *et al.,* 2009, 2018, 2019a, 2019b; Kolisoja *et al.,* 2015; Kalliainen and Kolisoja, 2015; Pekkala and Haataja, 2014, 2018, 2019; Pirjo and Asko, 2020; TTY, 2022).

Table 12. Measurement methods used in HCT projects

	Examples and alternatives:	Sensors installed at the site (point based measurements)	Measuring vehicles / Crowdsourced measurement	Measuring station (Perco station, weather station, etc.)	Laboratory measuments
TRAFFIC LOAD EFFECTS					
Traction deformation of the underside of the coating in longitudinal and transverse directions	Elongitation/compression of the underside of the coating in longitudinal and transverse directions (H-strain gauge)	x			
Direct measurement of elasticity compressions of the coating as well as other layers (modules, temperature and stress status dependence)	Elongitation/compression of the top surface of the coating in longitudinal and transverse directions using strain gauge. In the experiment, strain gauges mounted on the gravel road bearing layer are also carried out. Accelerometers have also been tried in both pavement and gravel roads	x			
Vertical stresses (pressures) prevailing in different layers and also horizontal stresses (within the resources)	Measurement of vertical stress (pressure) with ground pressure sensors	x			
Compressions of layers, Road surface grooving, vertical transitions, ridge height in gravel roads	Compression sensors at different layers of road structure, Laser scanning (increase in groove depth) in measuring vehicle, including Photography/Video+AI	x	x		
lateral transitions in road structures	steel balls and manual ground radar (trial [4])	x			
Moisture profiles of road pavement & other structures and subsoil	Ground radar (changes in humidity modes) in measuring vehicle, also Heat camera. Dielectric value and electrical conductivity from several depths in Perco-station		x	x	
Pore water pressure	Pore water pressure from structures of different depths	x			
CONDITIONAL FACTORS					
air temperature	temperature sensor for strain gauges, weather station, perco-station etc.	x		x	
rainfall, air humidity	From own measuring point next to the road/weather station	x		x	
Material and layer thicknesses of road structures and subsoil	Sampling, Deflection measurements, Ground penetration radar (GPR)	x	x		
Load capacity of road structures and subsoil	Deflection measurements: Falling Weight Deflectometer (FWD), Light Weight Deflectometer (LWD), Dynamic Cone Penetrometer (DCP) and Traffic Speed Deflectometer (TSD)		x		
Groundwater level	Point measurement of groundwater depth or information from the nearest official measuring station	x			
Temperature of road structures as a function of depth, includes the definition of the depth of the freezing front	Ground penetration radar (GPR) with measuring car or perco station/weather station	x	x	x	
Moisture of unbound layers and subsoil	Specified from samples as part of grain size distribution definition				x
Other laboratory test methods	partly based on the material: grain size distribution, Capillary rise measurement, CBR measurement, Triaxal measurement, Frost susceptibility, etc.				x
TRAFFIC & DRIVING MANNER FACTORS					
Vehicle measurements	e.g. Total and axle weights, tyre pressures		x		
Driving (line) measurements	Distance of tyres from the side of the road and the vehicle path by means of a laser (located on the edge of the road), precision GPS (located in vehicle), photos, video or (manual) tape measure	x	x		
Other measurements: Visual case by camera observation (e.g. observation of vehicle axle structure and load degree)	According to needs	x			

Survey and monitoring techniques in low-volume road structure research projects in ROADEX include the usage of the dynamic cone penetrometer (DCP). Peat road and peat investigation and survey techniques include desk study, site visit and walkover, probing, sampling, usage of ground penetration radar (GPR), usage of digital video, penetration testing, falling weight deflectometer, and accelerometer/profilometer, as well as several laboratory test methods (survey and monitoring techniques; roads on peat, investigations and surveys).

The above measurements and measurement results are utilized, for example, through Artificial Intelligence (AI) and machine learning to model road behavior (e.g., TUT; Kalliainen and Haakana, 2015; Kolisoja, 2019; Kolisoja *et al., 2015*; Kolisoja, 2012) and road life cycle management (e.g., Roadscanners), as well as to model and forecast road conditions and weather (e.g., Finnish Meteorological Institute; Vuorimies *et al.,* 2019b; Karsisto, 2022).

4.3.4. Key Findings

Effect of increasing the total mass and number of axles of vehicle combinations on rutting on different road types

According to road stress studies, even large HCT combinations do not increase the rutting of thick-paved roads. On the thickest part of thin-paved roads, road stress does not increase, but determining roads suitable for different sizes of HCT vehicle combinations requires refinement. For gravel roads and bridges, further research is also necessary. With driving line choices, drivers are able to influence permanent vertical transitions and rutting growth. A summary of the results is shown in *Table 13*.

Table 13. Summary of HCT-related survey results about road and bridge wear (Vänäläinen, 2022)

State roads with thick pavement	State roads with thin pavement	Gravel roads
No differences in rutting (1, 3)	Differences in rutting, depending on the thickness of the pavement (1, 2, 3) Ongoing research by Tampere University of Technology	Partly contradictory results (2, 3)
	⇨ Need to specify rutting impacts ⇨ Need for research on impacts on municipal roads	⇨ Need for further research
Ongoing Winter Premium project by University of Oulu and Finnish Meteorological Institute => Higher weight restrictions when road structure is frozen		

1= Vuorimies *et al*. (2018), 2 = Vuorimies *et al.* (2019), 3 = Pekkala and Haataja (2018)

On roads with thin pavement and poor load-bearing subsoil, an increase in the number of axles accelerates the rutting process of the road relative to the mass passing over the target. For roads with thick pavement and good load-bearing subsoil, there is little observed difference (Vuorimies *et al.,* 2019b).

From the measurements of the Pisantie gravel road, it seems that when driving along the same groove on a gravel road, the groove depths and ridge height increase. The change is significant in the peat-based section, and for the moraine rubber, the change is proportionally smaller (Pekkala and Haataja, 2019).

From the measurements of the Pisantie gravel road, it appears that when driving next to the formed groove, the initial groove depth decreases (the ridge height does not) (Pekkala and Haataja, 2019).

On gravel roads/forest roads, no significant differences in road-carrying resistance are obtained in measurements of 84-t versus 80-t versus 76-t vehicle combinations. However, it is noted that it is worth driving the vehicle combination on low load bearing sections of the road, preferably at a relatively high speed and avoiding stops (Pekkala and Haataja, 2019).

Pumping

Pumping under the influence of several successive heavy axle loads can cause very rapid road damage on thin-structure roads overlying soft and wet subsoil (TTY, 2022).

Tire types

The road stress effect of narrow single wheels at high atmospheric pressure is multiple times more than that of a double wheel load; new generation, wide single wheels have a load effect that is almost equivalent to that of double wheels (TTY, 2022).

Central Tire Inflation System (CTIS)

The greatest benefits of the CTI automatic tire pressure control system are achieved in poor load-bearing conditions on gravel/forest roads. It is advisable to use the system to reduce the pressure when a combination of vehicles comes from the (paved) main road to the forest road and to increase the pressure when returning to the main road. The pressure lowering/lifting operation takes time, so it was practically done during the vehicle progression, which is not the optimal solution.

ATWheels

Based on the measurements of the Pisantie gravel road (subsoil: peat), it seems that when driving along a formed groove with a combination of an ATWheels trailer, the increase in groove depth and ridge height slows down (Pekkala and Haataja, 2019).

Road topography and dynamic load caused by heavy traffic

During the days of measurements on the Pisantie gravel road, changes in the surface of the road, both grooves and bumps, were noted. The appearance of grooves and bumps had a distinct dependence on the road topography. The stress points caused by heavy vehicles included lateral stress on bends (outer curve) and longitudinal stress on uphill parts (acceleration). The bumps created as a result of the strain then caused additional dynamic stress (suspension), leading to an increase in damage. The driving direction also seemed to play a role in the development of groove depth (and ridge height).

5. Discussion

In attempting to deepen the understanding of first-mile challenges of agri-logistics, in the present study, we make contributions in the following ways:

- We identify the challenges of first-mile logistics in the agriculture industry by scanning scientific and gray literature and other types of resources.
- We propose a categorization structure for the identified challenges and conduct a hierarchical cluster analysis.
- We redefine a completely sequential process at the upstream level of the ASC and propose an update for the scheme.
- We determine the evidence levels of the sources chosen for this study, rank their information value, and define the dominance levels of the defined challenges.
- We compile the first-mile challenges that are defined and recognized by the industrial partners.
- We develop a QFD framework to be used by the industrial partners for the purpose of tackling the defined challenges.
- Finally, we compile a body of knowledge regarding simulation and testing in soil–machine interaction on sensitive grounds as link between WPs.

In the study, 93 challenges of first-mile logistics in the agriculture industry are identified and grouped into 6 distinct but overlapping categories. The identified first-level categories are *supply chain management and logistics*, *infrastructure*, *regulations*, *economics, business and finance*, *natural environment and phenomena,* and *skill set and workforce*. The challenges differ in their detailed level; for instance, some of the challenges, such as *exploitation of intermediaries and lack of competition among them*, are at the detailed level, while others are high-level concepts, such as *climate change*. A wide spectrum of the variety of challenges can be observed as well. Some challenges, particularly under the natural environment and phenomena, can be technical, while others are highly related to the financial situation of the stakeholders. In the first phase of the study, challenges in agriculture logistics at the first-mile stage of the SC were identified; therefore, they may relate to different stakeholders that may or may not be directly related to agricultural machinery and equipment. The scope of the challenges is narrowed down to the application of the QFD method on a company-specific basis. Additionally, we infer strong relations between and among the challenges, and their interplay is not stressed in this report; nevertheless, this can be examined through further reports as additional deliverables. As for the clusters, even though enough evidence has always been found to categorize a certain challenge under one of the themes and subthemes, they are inherently overlapping and can be interpreted differently by different researchers and experts. The categories differ in their scope and number of challenges as well. Thus, the categories do not follow the rule of having the same number of challenges. For instance, the cluster of *regulations* consists of seven challenges, yet we conclude that these challenges cannot be part of any other cluster; thus, a new cluster is now created and called *regulations*. A similar approach is applied to the category of skill set and workforce, which lacks subgroups and has merely five challenges.

The literature suggests the SC model with sequential transportation at the upstream level. However, as a result of discussions with our industrial partners, we suggest a hybrid model of the SC for the literature, as shown in *Figure 18*, which is more realistic. Some of the produce after harvesting are spared for seeding; thus, there is circular transportation between the production and the storage / processing stages of the SC, as indicated by one of our industrial partners, Company A.

In this report, we utilize a wide variety of sources, ranging from peer-reviewed scientific articles to project reports. For this reason, we have come to the conclusion that evidence-based ranking of sources is needed for the sake of differentiating sources with high levels of reliability, such as meta-analysis, from subjective reports. Despite the low evidence level of subjective reports, it does not mean that they bear no value, yet differentiation is needed, and those reports should be taken into consideration as well. For this purpose, we have developed a mathematical equation with a weightage system to identify the dominance levels of the challenges, based on the number of references and the evidence level of each reference that a challenge receives. The most evident challenge is *too long logistics / SC and excessive circulation links*; this challenge has been mentioned in seven sources from our research pool. The top 10 challenges with the highest rankings are as follows: *heavy wastage throughout the SC, complex and poor road network and infrastructure, extreme weather, water scarcity and access to fresh water, soil compaction, cost in SC, long duration of infrastructure projects, challenges related to cold chain* and *large number of marketing channels and restricted access to markets of agri-produce*. All of the challenges are ranked and grouped based on their dominance levels. The results of the information value assessment are later used in the QFD tool as well.

The identified challenges were presented to the industrial partners for their opinions, and they were asked to rank the challenges from *not important* to *crucial* (or *important*). They were asked to exclude the challenges about which they had no information. They were also given the option to add new challenges to the list. Overall, 2 of the 4 industrial partners joined this evaluation. In total, 65 challenges were ranked by at least one of the industrial partners as either *important* or *crucial*.

Company A marked 56 of the 93 challenges as either *important* or *crucial*, and Company B marked 33 challenges as either *important* or *crucial*. Company B also added 5 more challenges to the list in total and acknowledged 38 challenges for further analysis. Overall, only 24 of the 93 challenges were marked as either *important* or *crucial* by both partners, and there was no challenge that both companies similarly marked as *crucial*. In contrast, when the identified challenges were presented to the interviewees in Turkey, even though the vast majority of the challenges were acknowledged, the crucial challenges for our industrial partners, such as soil compaction, did not seem to be in their agenda at all. This implies a global inquiry of this challenge: "How much is soil compaction—in the context of agriculture—in the agenda of stakeholders?"

The QFD tool is used as an example for the industrial partners, ready to be used or updated for their further needs. The tool excludes the challenges that the partners previously lacked information about or did not find important in their particular fields. The tool takes the dominance levels of the challenges and the relevance to the partners' competitive advantage and inquiries about the prioritization levels of the challenges for the partners, in addition to the difficulty level of implementing an action to tackle the identified challenges. The work method of this WP is divided into joint research and company-specific reports based on the industrial partners' exclusive information needs. Since this report is guided by a joint research endeavor, after the QFD implementation for both partners, it is concluded that cost-friendly equipment that causes as little soil compaction as possible under varied weather conditions (aka extreme weather conditions caused by climate change) is needed, and further tests and analyses are required in different parts of the world, particularly in northern Europe. In addition to the applied methods, a body of knowledge regarding simulation and testing in soil–machine interaction on sensitive grounds is also compiled in this report. For detailed information about this, please check *Chapter 4*.

6. Conclusions

6.1. Testing and modeling soil–machine interaction

The first-priority challenges of first-mile agri-forestry logistics that can be at least partly overcome by machine designs are highlighted below.

Soil compaction seems to be a major problem, especially in agriculture, that is, on fields and croplands. Soil compaction reduces the quality of soil and thus decreases crop yields. The research and experiences also imply that soil compaction affects the infiltration of precipitation by reducing the absorption capacity and increasing the surface erosion of soil. Therefore, understanding the soil–machine interaction is one of the relevant issues of machine, tyre, and traction design. The models of soil compaction are available, and classical geoengineering tools and models may be used. However, since most of these tools and models have been primarily developed for road and ground surface transportation engineering, the models most likely require some calibration. Calibration in turn calls for in situ measurements of machine movement impacts on soil compaction and absorption capacity. The measurements should also include subsurface compaction below 30 cm from the surface. Again, traditional geotechnical site measurement tools can be used for sampling and testing, as well as for installing sensors in the soil bed.

Another important soil impact feature is the shredding of the surface soil. This is where the actual mechanical traction solutions play a role. While track-type mechanics seem to reduce soil compaction, and especially subsoil compaction, the surface impacts are negative. Shredding of the soil surface makes the fields more susceptible to soil erosion.

Climate change and extreme weather phenomena contribute to both soil compaction and soil erosion. Extreme precipitation increases soil erosion and reduces the soil's bearing capacity. It also loosens the surface and increases shredding effects. When extreme drought is experienced, and the soil is very dry or even hard, it is important to avoid the shredding effect as the dry, hard soil surface will not absorb heavy precipitation very quickly, and soil erosion occurs again as water is flushed away from the fields.

Regarding forest environments, the research data are scarce. Very few soil–machine analyses have been conducted; in fact, no significant studies are tracked down in this report. Most likely, the relevant machine–soil impacts concern the effects on surface vegetation and how much it suffers from machine movements. The only way to measure and model these types of impacts is basically visual observation, as well as expert evaluation based on it. The automation of such impact observations could prospectively make use of visual pattern recognition and some analysis algorithms. However, this area of research is new and exploratory. Intuitively, one is tempted to assume that rubber tire solutions have many advantages compared with track alternatives. Nonetheless, research and experimentation are required.

The abovementioned observation applies also to peatlands—the measurements of soil compaction and bearing capacity are difficult to carry out with the existing equipment and tools, and the modeling requires calibration of the existing models.

For low-volume gravel or access roads that serve the first mile, the tools and models are already available. There is also a long tradition of measuring traffic impacts on those roads. However, as climate warming will shorten the time windows for some forest operations (e.g., transportation of timber that is enabled by frozen ground with higher load-bearing capacity), the frost behavior of roads is an emerging field of research. Some progress in the modeling has been made, and field measurement tools have been developed.

Table 14 summarizes some examples of the state-of-the-art possibilities for modeling and measurement of soil impacts. However, these need to be decided on a case-by-case basis, depending on the information that a researcher wants to extract. Low-maturity means are mentioned in parentheses.

Table 14. Measurement and modelling based on soil type

	Soil Type		
	Agri-Field	Forest and Peatland	Non-Paved Access Roads
Field Measurements	• Pressure plates for soil compaction • Drill sampling and laboratory testing for compaction and water absorption • Visual observation for shredding	• Visual observation and qualitative assessment • (Machine vision and algorithms)	• Pressure plates • Tension sensors • Frost-heave machine
Modelling (Virtualisation)	• Geotechnical models (e.g., Odemark's formula) • Finite Element Methods and other structural modelling tools	• None	• Structural modelling • Thermo-dynamics

When making measurements for modelling, it is important to cover a sufficiently wide variety of contextual conditions. For example, in agri-fields, different soil moisture conditions are needed, and for access roads, the seasonal coverage (winter–summer) is essential.

For modelling itself, at least two primary strategies are available: deterministic and probability-based approaches. The deterministic approach often leads to regression curves that can be interpolated and extrapolated, whereas the probability-based approach typically leads to Markov chains and Monte Carlo simulations. The third approach could possibly be based on decision rules utilizing entropy analysis and algorithms. The first mentioned approach is the most straightforward and likely to require the least amount of measurement data, at least for robust modelling.

When measurements of soil impacts, machine performance, and contextual factors (soil moisture, temperature, type of machine solution, etc.) are combined, the arguments for alternative machine solutions can be affirmed.

6.2. Finding marketing strategies

As LEVITOI is seeking virtualization approaches to strengthen sales arguments and competitive edges of agri-forest machine solutions, it is essential to differentiate among markets. Socioeconomics, market structures, cultures, and traditions, as well as regulatory conditions, vary from region to region and from country to country. In Europe, climate change and environmental awareness is very high, so sustainability arguments resonate reasonably well with the public. However, even within Europe and the EU, the differences are substantial between north and south and equally so between east and west.

Based on the information collected in WP1, including all the sources, we propose the following framework, as presented in Table 15. This framework reflects our perceptions and should be regarded as such.

Table 15. Procurement arguments versus sales arguments

	Procurement Arguments			
Sales Arguments	**Not decisive**	**Somewhat decisive**	**Strongly decisive**	**Crucial**
Environment	EU East	EU South	EU North EU West	
Cost effectiveness	EU East	EU South	EU North EU West	
Upfront investment (price)		EU North EU West	EU South	EU East

References

African Development Bank. (2010). African Development Bank Group Agriculture Sector Strategy 2010–2014. Agriculture and Agro-Industry Department and Operational Resources and Policies Department.

Ahmed, U.I., Ying, L., Mushtaq, K., and Bashir, M.K. (2015). An econometric estimation of post-harvest losses of kinnow in Pakistan. *International Journal of Economics, Commerce & Management*, 3, 373–383.

Alaoui, A. and Diserens, E. (2018). Mapping soil compaction – A review. *Current Opinion in Environmental Science and Health*, 5, 60–66. https://doi.org/10.1016/j.coesh.2018.05.003

Alaoui, A., Lipiec, J., and Gerke, H.H. (2011). A review of the changes in the soil pore system due to soil deformation: A hydrodynamic perspective. *Soil and Tillage Research*, 115–116, 1–15. https://doi.org/10.1016/j.still.2011.06.002

Alexandre, M. (2020). EIP-AGRI Focus Group – Reducing food loss on the farm. *European Network for Rural Development*. Available at: https://policycommons.net/artifacts/2013788/eip-agri-focus-group/2766231/ (Accessed: 25.01.2023).

Alexandrou, A., Earl, R., and Gemtos, T.A. (2002). In situ assessment of soil compactibility. *ASAE Annual Meeting*. American Society of Agricultural and Biological Engineers. https://doi.org/10.13031/2013.9296

Amiama, C., Pereira, J.M., Castro, A., and Bueno, J. (2015). Modelling corn silage harvest logistics for a cost optimization approach. *Computers and Electronics in Agriculture*, 118, 56–65. https://doi.org/10.1016/j.compag.2015.08.024

Angelucci, F., Balié, J., Gourichon, H., Aparisi, A.M., and Witwer, M. (2013). Monitoring and analysing food and agricultural policies in Africa. MAFAP Synthesis Report 2013. MAFAP Synthesis Report Series, FAO, Rome, Italy.

Asian Development Bank (2016), Improving logistics for perishable agricultural products in the People's Republic of China.Asian Development Bank, Mandaluyong City, Philippines. Available at: https://rksi.adb.org/wp-content/uploads/2021/01/2016-Report-improving-logistics-agriculture.pdf (Accessed: 25.01.2023).

Awan, S., Ahmed, S., Ullah, F., Nawaz, A., Khan, A., Uddin, M.I., Alharbi, A., Alosaimi, W., and Alyami, H. (2021). IoT with blockchain: A futuristic approach in agriculture and food supply chain. *Wireless Communications and Mobile Comput*ing, 1–14. https://doi.org/10.1155/2021/5580179

Bakst, D. (2016). Eliminating and reducing regulatory obstacles in agriculture. The Heritage Foundation. Available at: https://www.heritage.org/government-regulation/report/eliminating-and-reducing-regulatory-obstacles-agriculture/#_ftn62 (Accessed: 25.01.2023).

Ball, B.C., Guimarães, R.M.L., Cloy, J.M., Hargreaves, P.R., Shepherd, T.G., and McKenzie, B.M. (2017). Visual soil evaluation: A summary of some applications and potential developments for agriculture. *Soil and Tillage Research*, 173, 114–124. https://doi.org/10.1016/j.still.2016.07.006

Banjo, G., Gordon, H., and Riverson, J. (2012). Rural transport: Improving its contribution to growth and poverty reduction in Sub-Saharan Africa. Sub-Saharan Africa Transport Policy Program (SSATP) working paper; no. 93. World Bank, Washington, D.C. Available at: https://openknowledge.worldbank.org/handle/10986/17807 (Accessed: 25.01.2023).

Bannor, R.K. and Kyire, S.K.C. (2021). A review on understanding blockchain technology in global supply chains; opportunities and challenges for agribusinesses. *Indian Journal of Economics and Development*, 917–927. https://doi.org/10.35716/IJED/21283

Bányai, T. (2018). Real-time decision making in first mile and last mile logistics: How smart scheduling affects energy efficiency of hyperconnected supply chain solutions. *Energies*, 11-7, 1833. https://doi.org/10.3390/en11071833

Bedord, (L. (2020). Drone use. Successful farming, 12 October. Available at: https://www.agriculture.com/technology/crop-management/drone-use (Accessed: 25.01.2023).

Berg, C.N., Blankespoor, B., and Selod, H. (2016). Roads and rural development in Sub-Saharan Africa. Policy Research Working Paper; No. 7729. World Bank, Washington, DC. Available at: https://openknowledge.worldbank.org/handle/10986/24646 (Accessed: 25.01.2023).

Bourne, M. (1977). Post harvest food losses—the neglected dimension in increasing the world food supply. Cornell International Agriculture Mimeograph 53. http://hdl.handle.net/1813/28900

Bradbury,A. (2018). The first mile: connecting rural communities to regional and urban markets. EST Forum 2018, Ulaanbatar Mongolia. Available at: https://www.uncrd.or.jp/content/documents/7126Presentation%204_The%20first%20mile%20connecting%20rural_Annabel.pdf (Accessed: 25.01.2023).

Cagliano, R., Worley, C.G., and Caniato, F.F.A. (2016). The challenge of sustainable innovation in agri-food supply chains. In: *Organizing for sustainable effectiveness*, pp. 1–30. Emerald Group Publishing Limited, Bingley. https://doi.org/10.1108/S2045-060520160000005009

Chaerani, D., Irmansyah, A.Z., Perdana, T., and Gusriani, N. (2022). Contribution of robust optimization on handling agricultural processed products supply chain problem during Covid-19 pandemic. *Uncertain Supply Chain Manag*ement, 10, 239–254. https://doi.org/10.5267/j.uscm.2021.9.004

Chai, L.C., Robin, T., Ragavan, U.M., Gunsalam, J.W., Bakar, F.A., Ghazali, F.M., *et al.* (2007). Thermophilic campylobacter spp. in salad vegetables in Malaysia. *International Journal of Food Microbiology*, 117, 106–111.

Commonwealth of Australia. (2016). Productivity Commission Inquiry Report Regulation of Australian Agriculture. Available at: http://www.itsanhonour.gov.au (Accessed: 25.01.2023).

Corrado, S. and Sala, S. (2018). Food waste accounting along global and European food supply chains: State of the art and outlook. *Waste Management*, 79, 120–131.

Craig, R.F. (2004). Craig's soil mechanics. 7th edn. Spon Press, New York, the USA.

Cue´llar, A.D. and Webber, M.E. (2010). Wasted food, wasted energy: The embedded energy in food waste in the United States. *Environmental Science & Technology*, 44, 6464–6469. doi:10.1021/es100310d

Dasgupta, S., Kanchan, S., and Kundu, T. (2019). Creating a KPI tree for monitoring and controlling key business objectives of first mile logistics services. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Bangkok, Thailand, March 5-7, pp. 716-727. Available at: http://www.ieomsociety.org/ieom2019/papers/206.pdf (Accessed: 25.01.2023).

Davidova, S. and Thomson, K. (2014). Family farming in Europe: Challenges and prospects, in-depth analysis. Directorate General for Internal Policies, Policy Department B: Structural and Cohesion Policies, European Parliament. Available at: https://www.europarl.europa.eu/RegData/etudes/note/join/2014/529047/IPOL-AGRI_NT(2014)529047_EN.pdf (Accessed: 25.01.2023).

De Pue, J. (2019). Advances in modelling vehicle-induced stress transmission in relation to soil compaction. *PhD Thesis, Ghent University*. Available at: https://biblio.ugent.be/publication/8631911/file/8631912.pdf (Accessed: 25.01.2023).

Department of Environmental Food and Rural Affairs UK. (2015). Cross compliance in England: Soil protection standards. www.gov.uk/government/collections/cross-compliance

Department of Infrastructure and Regional Development (2017). Technology and supply chains for critical industries agriculture sector (Working Paper 2 of 3). Department of Infrastructure and Regional Development Agriculture Sector, Australia. www.pwc.com.au

Despoudi, S. (2021). Challenges in reducing food losses at producers' level: The case of Greek agricultural supply chain producers. *Industrial Marketing Manag*ement, 93, 520–532. https://doi.org/10.1016/j.indmarman.2020.09.022

Easdown, W. and Acedo, A. (2015). Post-harvest losses of vegetables in South Asia (Vol. 32, Issue 2). www.assocham.org.

European Commission, Joint Research Centre, Vranken, L., Roebeling, P., Tabeau, E. et al. (2021). Agricultural land market regulations in the EU members. Publication Office: Available at: https://doi.org/10.2760/86127 (Accessed: 27.01.2023).

European Commission (2022). Short-term outlook for EU agricultural markets. https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/markets/outlook/short-term_en

European Environment Agency (2022). Economic losses and fatalities from weather- and climate-related events in Europe. Briefing. Available at: https://www.eea.europa.eu/publications/economic-losses-and-fatalities-from (Accessed: 26.01.2023).

European Union. (2017). State of play of farmland concentration in the EU: How to facilitate the access to land for farmers (2016/2141(INI)).

Fakava, V.T. (2012). Climate change impact on agriculture and food security. In Regional Training Workshop on Adaptation for the Pacific Least Developed Countries. Available at: https://unfccc.int/sites/default/files/leg_2012_pacific_workshop_fao_presentation.pdf (Accessed: 26.01.2023).

FAO (2015). Climate change and food security: Risks and responses. Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/i5188e/I5188E.pdf (Accessed: 26.01.2023).

Food and Agriculture Organization (FAO). (2013). *Food wastage footprint: Impacts on natural resources.* Technical Report. Rome: Food and Agriculture Organization of the United Nations. http://www.fao.org/docrep/018/ ar429e/ar429e.pdf

FAO. (2017). The future of food and agriculture and challenges. Rome: Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/i6583e/i6583e.pdf (Accessed: 26.01.2023).

FAO (2019). The state of food and agriculture 2019 - Moving forward on food loss and waste reduction. Rome: Food and Agriculture Organization of the United Nations. Available at: https://www.fao.org/3/ca6030en/ca6030en.pdf (Accessed: 26.01.2023).

Frelih-Larsen, A., Schjønning, P., Lamandé, M., and Hvarregaard, M. (2018). Policy brief subsoil compaction – a threat to sustainable food production and soil ecosystem services. Available at: https://www.ecologic.eu/sites/default/files/publication/2018/2730_recare_subsoil-compaction_web.pdf (Accessed: 26.01.2023).

Gardas, B.B., Raut, R.D., Cheikhrouhou, N., and Narkhede, B.E. (2019). A hybrid decision support system for analyzing challenges of the agricultural supply chain. *Sustainable Production Consumption*., 18, 19–32. https://doi.org/10.1016/j.spc.2018.11.007

Giovannucci, D., Scherr, S., Nierenberg, D., Hebebrand, C., Shapiro, J., and Milder, J. (2012). Food and agriculture: The future of sustainability. *Sustainable Development in the 21st century (SD21) Report for Rio+20*, New York: United Nations. Available at: http://dx.doi.org/10.2139/ssrn.2054838 (Accessed: 26.01.2023).

Gleeson, E. and O'Beirne, D. (2005). Effects of process severity on survival and growth of Escherichia coli and Listeria innocua on minimally processed vegetables. *Food Control*, 16, 677–685.

Government of India. (2019). Training programme on supply chain management in agriculture reading material. www.manage.gov.in

Gray, B., Babcock, L., Tobias, L., and McCord, M. (2018). Digital Farmer Profiles: Reimagining smallholder agriculture. Feed the Future, The U.S. Government's Global Hunger & Food Security Initiative. Available at: https://grameenfoundation.org/documents/Data_Driven_Agriculture_Web.pdf (Accessed: 26.01.2023).

Han, J.-W., Zuo, M., Zhu, W.-Y., Zuo, J.-H., Lü, E.-L., and Yang, X.-T. (2021). A comprehensive review of cold chain logistics for fresh agricultural products: Current status, challenges, and future trends. *Trends Food Science and Technology*, 109, 536–551. https://doi.org/10.1016/j.tifs.2021.01.066

Hemmat, A. and Adamchuk, V.I. (2008). Sensor systems for measuring soil compaction: Review and analysis. *Computers and Electronics in Agriculture*, 63(2), 89–103. https://doi.org/10.1016/j.compag.2008.03.001

Horn, R., Domzzał, H., Słowińska-Jurkiewicz, A., and van Ouwerkerk, C. (1995). Soil compaction processes and their effects on the structure of arable soils and the environment. *Soil and Tillage Research*, 35(1–2), 23–36. https://doi.org/10.1016/0167-1987(95)00479-C

Iimi, A., You, L., Wood-Sichra, U. and Humphrey, R.M. (2015). Agriculture production and transport infrastructure in East Africa: An application of spatial autoregression. World Bank Group. https://elibrary.worldbank.org/doi/pdf/10.1596/1813-9450-7281

International Labour Organization. (2017). Food and agriculture global value chains: Drivers and constraints for occupational safety and health improvement. Volume One. Perspectives from relevant research areas.

Isbister, B., Blackwell, P., and Riethmuller, G. (2013). Controlled Traffic Farming Technical Manual. Available at: https://www.nacc.com.au/wp-content/uploads/2015/05/NACC_Controlled_Traffic_Farming_Technical_Manual.pdf (Accessed: 26.01.2023).

Jacxsens, L., Luning, P.A., van der Vorst, J.G.A.J., Devlieghere, F., Leemans, R., and Uyttendaele, M. (2010). Simulation modelling and risk assessment as tools to identify the impact of climate change on microbiological food safety – The case study of fresh produce supply chain. *Food Research International*. 43, 1925–1935. https://doi.org/10.1016/j.foodres.2009.07.009

JRC Technical Report (2020). Analysis of climate change impacts on EU agriculture by 2050. European Commission. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC119632 (Accessed: 26.01.2023).

Johansson, S., Johansson, K., and Ekedahl, F. (2007). Policies for forest roads – Some proposals, November 2007. ROADEX Publications. https://www.roadex.org/wp-content/uploads/2014/01/Rehabilitation-of-the-Timmerleden-Forest-Road-design-proposals-2011.pdf

Kalliainen, A. Kolisoja, P. and Haakana, V. (2015). Effect of tire configuration on the performance of a low volume road exposed to heavy axle loads: Mechanical modelling. Transportation Research Record, 2474 (1), pp. 174-184. https://doi.org/10.3141%2F2474-21

Karsisto, V. (2022). Finnish Meteorological Institute. Modification of the FMI Road Weather model to forecast spring thaw weakening – literature overview. Available at: https://winterpremium.fmi.fi/Karsisto_Literature_overview_gravel_road_modeling.pdf (Accessed: 26.01.2023).

Keller, T. (2004). Soil compaction and soil tillage – Studies in agricultural soil mechanics. Doctoral Thesis, Department of Social Sciences. Swedish University of Agricultural Sciences. Available at: https://pub.epsilon.slu.se/673/1/TK_Agraria_489.pdf (Accessed: 26.01.2023).

Kirubi, M. and Burrows, G. (2015). Strengthening the first mile. Enabling small and medium agribusinesses to unlock development in Tanzania, Uganda and Kenya. Farm Africa. Available at: https://www.farmafrica.org/downloads/resources/strengthening-the-first-mile---pages.pdf (Accessed: 26.01.2023).

Kolisoja, P. (2012). Mode 2 rutting design approach. Description of the new ROADEX design approach for mode 2 rutting on low volume roads. Research report. ROADEX. Available at: https://www.roadex.org/wp-content/uploads/2014/01/ROADEX_report_Mode_2_rutting_design_approach.pdf (Accessed: 26.01.2023).

Kolisoja, P. (2019). Tampereen yliopisto. Kasvavat ajoneuvopainot ja sorateiden kuormituskestävyys. s. 17/22: Laskentamenettely sorateiden kuormituskestävyyden arviointiin. Soratiepäivä 16.5.2019 Jyväskylä.

Kolisoja, P., Kalliainen, A., and Haakana, V. (2015). Effect of tire configuration on the performance of a low volume road: Response measurements. *Transportation Research Record*, 2474 (1), pp.166-173. https://doi.org/10.3141%2F2474-20

Kresnanto, N.C., Putri, W.H., Lantarsih, R., and Harjiyatni, F.R. (2021). Challenges in transportation policy: Speeding up a sustainable agri-food supply chain. IOP Conference Series: Earth and Environmental Science 662, 012006. https://doi.org/10.1088/1755-1315/662/1/012006

Kurnik, B. (2019). Climate change adaptation in the agriculture sector in Europe. European Environment Agency, Report No 4/2019. Available at: https://www.eea.europa.eu/publications/cc-adaptation-agriculture (Accessed: 27.01.2023).

Kärenlampi, R. and Hänninen, M.-L. (2004). Survival of Campylobacter jejuni on various fresh produce. *International Journal of Food Microbiology*, 97, 187–195.

Lamandé, M., Schjønning, P., and Labouriau, R. (2017). A novel method for estimating soil precompression stress from uniaxial confined compression tests. *Soil Science Society of America Journal*, 81 (5), pp. 1005-1013. doi:10.2136/sssaj2016.09.0274

Lezoche, M., Hernandez, J.E., Alemany Díaz, M. del M.E., Panetto, H., and Kacprzyk, J. (2020) Agri-food 4.0: A survey of the supply chains and technologies for the future agriculture. *Computers in Industry*, 117, 103187.

Lingjuan, T., Linhong, L., and Menghan, L. (2018). Optimization of the front-end logistics routes of agricultural products based on network platform. International Journal for Engineering Modelling, 31 (4), Special Issue. https://doi.org/10.31534/engmod.2018.4.si.01g

Liu, Y., Ma, X., Shu, L., Hancke, G.P., and Abu -Mahfouz, A.M. (2021). From Industry 4.0 to Agriculture 4.0: Current status, enabling technologies, and research challenges. *IEEE Transactions on Industrial Informatics*, 17 (6), 4322–4334.

Ludwig, C., Nagarajan, G., and Zaman, L. (2016). Systematic review of the effects of rural roads on expanding agricultural markets in developing countries. U.S. Department of Agriculture, Foreign

Agricultural Service. Available at: https://www.fas.usda.gov/sites/default/files/2020-03/ffpr_roads_systematic_review_final.pdf (Accessed: 27.01.2023).

Macioszek, E. (2018). First and last mile delivery – Problems and issues. In: Sierpiński, G. (Ed.), *Advanced solutions of transport systems for growing mobility, advances in intelligent systems and computing,* pp. 147–154. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-62316-0_12

Majluf-Manzur, Á.M., González-Ramirez, R.G., Velasco-Paredes, R.A., and Villalobos, J.R. (2021). An operational planning model to support first-mile logistics for small fresh-produce growers. In: Rossit, D.A., Tohmé, F., and Mejía Delgadillo, G. (Eds.), *Production research, communications in computer and information science,* pp. 205–219. Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-76310-7_17

Metsäteho. (2022). Puutavaran ja hakkeen HCT-yhdistelmien tutkimus. https://www.metsateho.fi/hct/

Ministry of Agriculture and Reforms, India. (2021). Annual report of agriculture system in India. https://agricoop.nic.in/sites/default/files/Web%20copy%20of%20AR%20%28Eng%29_7.pdf

Mirabelli, G. and Solina, V. (2020). Blockchain and agricultural supply chains traceability: Research trends and future challenges. *Procedia Manufacturing*, 42, 414–421. https://doi.org/10.1016/j.promfg.2020.02.054

Mousavi-Avval, S.H. and Shah, A. (2020). Techno-economic analysis of pennycress production, harvest and post-harvest logistics for renewable jet fuel. *Renewable Sustainable Energy Reviews*, 123, 109764. https://doi.org/10.1016/j.rser.2020.109764

Munro, R. and MacCulloch, F. (2008). Tyre pressure control on timber haulage vehicles. Some observations on a trial in Highland, Scotland. February 2008. ROADEX Publications. https://www.roadex.org/wp-content/uploads/2014/01/TPCS-Trial-RIII.pdf

Naseer, M., Ashfaq, M., Hassan, S., Abbas, A., Razzaq, A., Mehdi, M., Ariyawardana, A., and Anwar, M. (2019). Critical issues at the upstream level in sustainable supply chain management of agri-food industries: Evidence from Pakistan's citrus industry. *Sustainability*, 11, 1326, pp. 1-19. https://doi.org/10.3390/su11051326

Obour, P.B., Schjønning, P., Peng, Y., and Munkholm, L.J. (2017). Subsoil compaction assessed by visual evaluation and laboratory methods. *Soil and Tillage Research*, 173, pp. 4-14. http://dx.doi.org/10.1016/j.still.2016.08.015

OECD/FAO. (2016). OECD FAO Guidance for Responsible Agricultural Supply Chains. https://doi.org/10.1787/9789264251052-en

Onggo, B.S., Panadero, J., Corlu, C.G., and Juan, A.A. (2019). Agri-food supply chains with stochastic demands: A multi-period inventory routing problem with perishable products. *Simulation Modelling Practice and Theory*, 97, 101970. https://doi.org/10.1016/j.simpat.2019.101970

Oyeyemi, K.D., Aizebeokhai, A.P., Adagunodo, T.A., Olofinnade, O.M., Sanuade, O.A., and Olaojo, A.A. (2017). Subsoil characterization using geoelectrical and geotechnical investigations: Implications for foundation studies. *International Journal of Civil Engineering and Technology*, 8(10), 302–314.

Parfitt, J., Brockhaus, A., and Croker, T. (2021). Driven to waste: The global impact of food loss and waste on farms. World Wildlife Fund. Available at: https://www.worldwildlife.org/publications/driven-to-waste-the-global-impact-of-food-loss-and-waste-on-farms (Accessed: 27.01.2023).

Patidar, R. and Agrawal, S. (2020). A mathematical model formulation to design a traditional Indian agri-fresh food supply chain: A case study problem. *Benchmarking: An International* Journal, 27, 2341–2363. https://doi.org/10.1108/BIJ-01-2020-0013

Patidar, R., Venkatesh, B., Pratap, S., and Daultani, Y. (2018). A sustainable vehicle routing problem for Indian agri-food supply chain network design, in: Proceedings of the 2018 International Conference on Production and Operations Management Society (POMS). IEEE, Peradeniya, Sri Lanka, pp. 1–5. https://doi.org/10.1109/POMS.2018.8629450

Pekkala, V. and Haataja, M. (2018). Tien rasitukset tieverkossa: HCT- ja muiden puunkuljetusyhdistelmien vaikutusten vertailu 2016-2017, loppuraportti, 2018. Oulun yliopisto, Juvenes Print 2018. Raportti n:o 7, ISSN 2342-2599, ISBN 978-952-62-2148-2

Pekkala, V. and Haataja, M. (2019). HCT-yhdistelmien vaikutus soratien urautumiseen, raportti, 2019. Oulun yliopisto, Juvenes Print 2019. Raportti n:o 10, ISSN 2342-2599, ISBN 978-952-62-2480-0

Pekkala, V. and Niskanen, P. (2014). Utilization of norther Finland's arctic conditions to increase transport capacity in heavy equipment transport (Winter Premium). Available at: https://www.eura2014.fi/rrtiepa/projekti.php?projektikoodi=A76018 (Accessed: 27.01.2023).

Permanent deformation, ROADEX e-learning material. https://www.roadex.org/e-learning/lessons/permanent-deformation/disclaimer

Petersen, C.T. and Abrahamsen, P. (2021). Predicting effects of soil compaction on crop yield and nitrogen dynamics. University of Copenhagen, Department of Plant and Environmental Sciences. Available at: https://daisy.ku.dk/about-daisy/projects/commit/Simulating_compaction_effects_gudp.pdf (Access: 27.01.2023).

Poodt, M.P., Koolen, A.J., and Van Der Linden, J.P. (2003). FEM analysis of subsoil reaction on heavy wheel loads with emphasis on soil preconsolidation stress and cohesion. *Soil and Tillage Research*, 73(1–2), 67–76. https://doi.org/10.1016/S0167-1987(03)00100-4

Porter, S.D. and Reay, D.S. (2016). Addressing food supply chain and consumption inefficiencies: Potential for climate change mitigation. *Regional Environmental Change*, 16, 2279–2290. https://doi.org/10.1007/s10113-015-0783-4

Raut, R.D., Gardas, B.B., Narkhede, B.E., and Jha, M.K. (2019). Analysing the challenges in sustainable agricultural supply chain system in India. *International Journal of Business Excellence*., 18 (3). https://doi.org/10.1504/IJBEX.2019.10022454

Roads on peat, investigations and surveys. ROADEX e-learning material. https://www.roadex.org/e-learning/lessons/roads-on-peat/investigations-and-surveys/

Roads on peat. ROADEX e-learning material. https://www.roadex.org/e-learning/lessons/roads-on-peat/

Sadati, A.K., Nayedar, M., Zartash, L., and Falakodin, Z. (2021). Challenges for food security and safety: A qualitative study in an agriculture supply chain company in Iran. *Agriculture & Food Security*, 10, Article no: 41. https://doi.org/10.1186/s40066-021-00304-x

Savolainen, M., Ryynänen, T., Belt, J., and Ehrola, E. (2001). Liikennekuormitusten määrittäminen tierakenteen vasteiden avulla [Determination of traffic loads from road structure responses]. Finnra Reports 22/2001. Helsinki: Finnish Road Administration.

Schjønning, P. and Lamandé, M. (2018). Models for prediction of soil precompression stress from readily available soil properties. *Geoderma*, 320, 115–125. https://doi.org/10.1016/j.geoderma.2018.01.028

Schjønning, P., Lamandé, M., Crétin, V., and Nielsen, J.A. (2017). Upper subsoil pore characteristics and functions as influenced by field traffic and freeze-thaw and dry-wet treatments. *Soil Research,* 55, 234–244. http://dx.doi.org/10.1071/SR16149

Schjønning, P., Lamandé, M., Keller, T., Pedersen, J., and Stettler, M. (2012). Rules of thumb for minimizing subsoil compaction. *Soil Use and Management*, 28(3), 378–393. https://doi.org/10.1111/j.1475-2743.2012.00411.x

Schjønning, P., Lamandé, M., Munkholm, L.J., Lyngvig, H.S., and Nielsen, J.A. (2016). Soil precompression stress, penetration resistance and crop yields in relation to differently-trafficked, temperate-region sandy loam soils. *Soil and Tillage Research*, 163, 298–308. http://dx.doi.org/10.1016/j.still.2016.07.003

Schjønning, P., van den Akker, J.J.H., Keller, T., Greve, M.H., Lamandé, M., Simojoki, A., Stettler, M., Arvidsson, J., and Breuning-Madsen, H. (2015). Driver-Pressure-State-Impact-Response (DPSIR) analysis and risk assessment for soil compaction—A European perspective. In: Sparks, D.L. (Ed.), *Advances in agronomy*, Vol. 133, pp. 183–237. Academic Press. http://dx.doi.org/10.1016/bs.agron.2015.06.001

Soto-Silva, W.E., González-Araya, M.C., Oliva-Fernández, M.A., and Plà-Aragonés, L.M. (2017). Optimizing fresh food logistics for processing: Application for a large Chilean apple supply chain. *Computers and Electronics in Agriculture*, 136, 42–57. https://doi.org/10.1016/j.compag.2017.02.020

Srivastava, A. and Dashora, K. (2022). Application of blockchain technology for agrifood supply chain management: A systematic literature review on benefits and challenges. *Benchmarking: An International Journal, 29(10), pp. 3426-3442.* https://doi.org/10.1108/BIJ-08-2021-0495

Stenmarck, Â., Jensen, C., Quested, T., Moates, G., Buksti, M., Cseh, B., ... and Östergren, K. (2016). Estimates of European food waste levels. Stockholm, IVL Swedish Environmental Research Institute.

Stettler, M., Keller, T., Weisskopf, P., Lamandé, M., Lassen, P., and Schjønning, P. (2014). Terranimo® – a web-based tool for evaluating soil compaction. *Landtechnik*, 69(3), 132–137.

Stichler, J.F. (2010). Weighing the evidence. *Health Environments Research and Design Journal*, 3(4), pp. 3-7. doi:10.1177/193758671000300401

Stolte, J., Tesfai, M., Øygarden L., Kværnø, S., and Keizer, J. (2016). Soil threats in Europe. https://publications.jrc.ec.europa.eu/repository/handle/JRC98673

Survey and monitoring techniques, ROADEX e-learning material. https://www.roadex.org/e-learning/lessons/permanent-deformation/survey-and-monitoring-techniques/

Tang, J., Liu, K., and Chen, Q. (2013). Study on cold chain logistics of vehicle routing problem for agricultural products. In: Proceedings of 2013 IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI), IEEE, Dongguan, China, 317–322. https://doi.org/10.1109/SOLI.2013.6611433

Tani Hub. (2020). Building sustainable agriculture supply chain in Indonesia through technology and innovations. Open Learning Campus, World Bank Group. Available at: https://olc.worldbank.org/system/files/TaniHub%20Final%20slide%20deck%20Aug%2013%202020.pdf (Accessed: 27.01.2023).

The Nordic Genetic Resource Center (2019). Nordic Agriculture and Climate Change: Mitigation and Adaptation Recommendations from leading researchers and private companies within the Nordic plant breeding, NordGen publication series: 2019:01. Available at: http://norden.diva-portal.org/smash/get/diva2:1314281/FULLTEXT02.pdf (Accessed: 27.01.2023).

TTY (2022). 9 ja 12 –akselisten ajoneuvoyhdistelmien kuormitusvaikutuksen vertailu parhaillaan käynnissä Karstulassa (Mt 697) Metsäteho Oy:n ja Väyläviraston toimeksiantona. Lähde Kolisoja HCT-tierasitustukkimukset 2022. Available at: https://www.metsateho.fi/wp-content/uploads/Kolisoja-HCT-tierasitustutkimukset.pdf (27.01.2023).

Tuure, V.-M., Lätti, M., and Kaila, E. (2016). Maatalousajoneuvojen liikenneturvallisuus. TTS Työtehoseura, kalvoesitys, Rajamäki 31.3.2016.

US Department of Agriculture. (2018). Regulatory improvement and reform: A priority for American agriculture. American Farm Bureau Federation. Available at: https://www.fb.org/files/AFBF_White_Paper_on_Regulatory_Reform.pdf (Accessed, 27.01.2023).

US Department of State. (2013). Postharvest loss challenges. Discussion Paper. Office of Agriculture, Biotechnology, and Textile Trade Affairs, Bureau of Economic and Business Affairs. Available at: https://2009-2017.state.gov/documents/organization/220958.pdf (Accessed: 27.01.2023).

US Department of Transportation. (2022). Supply chain assessment of the transportation industrial base: freight and logistics. Available at: https://www.transportation.gov/supplychains (Accessed: 27.01.2023).

Van Den Akker, J.J.H. (2004). SOCOMO: A soil compaction model to calculate soil stresses and the subsoil carrying capacity. *Soil and Tillage Research*, 79(1), 113–127. https://doi.org/10.1016/j.still.2004.03.021

Van Dusen, N. and Beyard, K. (2013). Post-Harvest Handling and Storage (PHHS) Project. Final Report. The United States Agency for International Development. Available at: https://pdf.usaid.gov/pdf_docs/pa00jfxn.pdf (Accessed: 27.01.2023).

Varin, P. and Saarenketo, T. (2014). Effect of axle and tyre configuration on pavement durability – a prestudy. Report 2014. ROADEX Publications. https://www.roadex.org/wp-content/uploads/2014/01/ROADEX_Axle_Tyre_Prestudy_15102014-Final.pdf

Vänäläinen, P. (2022). Metsäteho Oy, Presentation in Road Congress, Maintenance and Asset Management Seminar, August 25, 2022, HCT-kokeilut Suomen puukuljetuksissa.

Venäläinen, P. and Asko, P. (2020). Puutavara- ja hakeajoneuvojen massojen noston vaikutukset. Metsätehon raportti 258 (aiheen 2. väliraportti) 18.11.2020. Metsäteho Oy (Verkkojulkaisu).

Violi, A., Laganá, D., and Paradiso, R. (2020). The inventory routing problem under uncertainty with perishable products: An application in the agri-food supply chain. *Soft Comput*ing, 24, 13725–13740. https://doi.org/10.1007/s00500-019-04497-z

Vuorimies, N., Kalliainen, A., Rossi, J., Kolisoja, P., Varin, P., and Saarenketo, T. (2018). Tierakenteen rasittuminen yli 76 tonnin HCT-yhdistelmien koekuormituksissa vuosina 2015 - 2017: Liikenneviraston tutkimuksia ja selvityksiä 63/2018. https://www.doria.fi/handle/10024/165324

Vuorimies, N., Kurki, A., Kolisoja, P., Varin, P., and Saarenketo, T. (2019a). *Strain on the road structure in stress tests for HCT combinations weighing more than 76 tonnes.* Research reports of the Finnish Transport Infrastructure Agency 17/2019. Helsinki: Finnish Transport Infrastructure Agency.

Vuorimies, N., Kurki, A., Kolisoja, P., Varin, P., Saarenketo, T., Pekkala, V., and Haataja, M. (2019b). *Road structure strain on test loads of more than 76 tons, HCT combinations in 2015–2018.* Research reports of the FTIA 21/2019. Helsinki: Finnish Transport Infrastructure Agency.

Vuorimies, N., Matintupa, A., Luomala, H. (2009). CTI-puutavara-autossa, Keuruun metsätien syksyn 2008 ja Vesilahden maantien kevään 2009 mittausten tulokset, Metsätehon raportti 207, Helsinki.

Wang, X.W. and Zhong, F.N. (2008). Land fragmentation and the land transfer market. *China Rural Survey*, 4, 29–34.

Wen, L., Ya-zi, W., and Xu, C. (2017). The coordination problem of fresh agricultural products supply chain with option contract based on product quality. In: Proceedings of the 2017 14th International Conference on Service Systems and Service Management (ICSSSM), IEEE, Dalian, China, pp. 1–6. https://doi.org/10.1109/ICSSSM.2017.7996276

World Bank. (2019). Enabling the Business of Agriculture 2019. Available at: https://eba.worldbank.org/en/reports (Accessed: 27.01.2023).

Xiao-yuan, S. and Wei-hua, Z. (2013). Agricultural products circulation problem analysis and optimization of logistics operations. In: Proceedings of the 2013 6th International Conference on Information Management, Innovation Management and Industrial Engineering (ICIII), IEEE, Xi'an, China, pp. 123–126. https://doi.org/10.1109/ICIII.2013.6703529

Xuezhen, G., Zhen, L., and Duivenvoorden, W. (2020). Market study on cold chain logistics in China. Commissioned by the Netherlands Enterprise Agency. https://doi.org/10.18174/530333

Yadav, S., Garg, D., and Luthra, S. (2020). Analysing challenges for Internet of Things adoption in agriculture supply chain management. International Journal of Industrial and Systems Engineering, 36 (1), pp. 73-97. https://doi.org/10.1504/IJISE.2020.109121

Yang, X., Fu, Z., and Zhang, J. (2014). Research on supply chain option problems of agricultural products in the perspective of farmer-supermarket direct purchase. *Open Cybernetics & Systemics Journal.,* 8, 805–812. https://doi.org/10.2174/1874110X01408010805