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Department of Security Studies

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2021 **Adam Hruška**

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Food Security and Machine Learning: Opportunities and Challenges

Master's thesis

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Declaration

1. I hereby declare that I have compiled this thesis using the listed literature and resources only.
2. I hereby declare that my thesis has not been used to gain any other academic title.
3. I fully agree to my work being used for study and scientific purposes.

In Prague on 29th May 2021

Adam Hruška

References

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Abstract

The emergence of the effects of global warming, as well as the ongoing depletion of fossil fuels and fertile soil pose a serious threat for the future of the agricultural industry. Alternatively, the continuous population growth mainly in the less developed regions highlights the future need of approximately 70-110 percent increase in the overall output of contemporary food production. While the current conventional agriculture deploys a multitude of technologies including the precision agriculture framework, the future needs of the population exceed the projected capabilities of the industry. Machine learning as the current fastest growing technology represents the potential remedy for the emerging issues, yet the extent of successful implementation remains uncertain.

The thesis aims to uncover the potential future implications of implementation of machine learning based technology in agriculture through the use of the new scenario building methodology. The analysis builds on a varying set of empirical data, current state of art projects in machine learning and multiple future trend projections. Albeit the scenario building technique allows for a potentially endless number of constructed scenarios, the thesis concentrates on three main plot lines. First scenario tackles the more probable optimistic perspective, while the second contains a similarly feasible, more reserved, and less optimistic future. Finally, the third scenario centres around a less probable future scenario filled with wild card events and unprecedented developments.

Both the issues including climate change and depletion of resources, as well as the use of machine learning in agriculture exist within the contemporary academic literature. Thus, the first three chapters contain the conceptual and methodological framework, as well as the review of the relevant literature. Even though the core of the thesis focuses on the future developments, the fourth chapter uncovers the empirical data used for the projection of observed trends and indication of potential emergent phenomena. Finally, the scenarios themselves are constructed in the final three chapters, while the chapter seven concludes the process through the uncovering of the “history of the future.

Abstrakt

Vzhledem k rostoucímu vlivu globálního oteplování a kontinuální závislosti na neobnovitelných zdrojích, jako jsou fosilní paliva či úrodná půda, existuje velmi reálná hrozba pro budoucnost agrární sféry. Vedle budoucích omezení ovšem dochází k stále stupňujícímu populačnímu růstu především v méně rozvinutých regionech, kdy řada odhadů poukazuje na nutnost 70-110 procentního nárůstu v produkčních kapacitách potravinové produkce v reakci na růst populace. Navzdory soudobým technologiím, mezi něž patří precizní zemědělství, lze s poměrně velkou jistotou očekávat nedostatečný růst produkce ve vztahu k růstu požadavků populace. Strojové učení, které v současnosti patří mezi nejvíce rozvíjené technologie, je považováno za potenciální řešení pro výše zmíněné hrozby, ovšem rozsah jeho úspěšného nasazení zůstává nejistý.

Hlavním cílem práce je zkoumání a rozbor potenciálních následků implementace strojového učení v agrární sféře, přičemž výzkum budoucnosti je realizován pomocí metodologického rámce nové scenáristiky. Analýza pro svůj cíl užívá řadu empirických dat, soudobé výzkumné projekty v rámci strojového učení a kombinaci projekcí současných fenoménů. Přesto, že metodologický rámec potenciálně umožňuje tvorbu neomezeného počtu scénářů, se práce soustředí na tři hlavní narativy. První ze scénářů se soustředí na pravděpodobnou, ovšem značně optimistickou budoucnost, kdy druhý ze scénářů naopak sleduje podobně pravděpodobnou, avšak nesrovnatelně méně optimistickou vizi. Závěrem se třetí ze scénářů věnuje mnohem méně pravděpodobné budoucnosti, která vzniká na základě řady divokých karet a extrémních hodnot proměnných.

Vzhledem k jejich významu jsou fenomény změny klimatu, závislosti na neobnovitelných zdrojích, podobně jako výzkum strojového učení, součástí soudobé akademické literatury. Na základě výše zmíněné literatury se první tři kapitoly práce zabývají konceptuálním a metodologickým rámcem i rozborem relevantních literárních zdrojů. Navzdory jednoznačnému zaměření analýzy na budoucí vývoj je čtvrtá kapitola postavena na rozboru soudobých trendů a jejich budoucí projekci, k níž je svázána i snaha o rozklíčování indikace budoucích fenoménů. Závěrečné kapitoly se již soustředí na samotnou konstrukci scénářů, přičemž sedmá kapitola uzavírá analýzu popisem takzvané „historie budoucnosti“.

Keywords

food security, machine learning, environmental sustainability, climate change

Klíčová slova

potravinová bezpečnost, strojové učení, udržitelnost životního prostředí, klimatické změny

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Název práce

Potravinová bezpečnost a strojové učení: Příležitosti a výzvy

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Introduction

While the world remains focused on the lessons of the past, the emergence of new threats highlights the importance of a future perspective combating that of a pure post hoc determinism. With the rise of global warming, the implications of the turbulently changing climate pose a risk for the continuous development of the dynamics of food security in continuous population growth. Even though the contemporary situation endangers only a limited number of less developed regions, which rely heavily on seasonal weather, the future implications of the observed trends pose a more global threat. As the estimated needs of a growth of food production outputs in order to feed the growing population range from 70 to 110 percent (Pretty 2008, p. 447-448), the indicated disruptions for the industry jeopardize the potential for the fulfilment of the aforementioned needs. Considering the emerging issues, the academic community suggests a major shift in paradigm from enhanced productivity to the ideal of full sustainability (Sharma et al. 2020, p. 1-2).

The core of the thesis is the exploration of the potential implications of the implementation of machine learning technology in the agricultural industry as a tool for mitigation of emerging global food insecurity. Construction of the potential future within the analysis stems from the use of the new scenario building methodology. Albeit the use of current empirical data serves only as a limited element of the process, the inclusion of the current research of the field remains important for the analysis. The resulting analytical process results in the first research question:

RQ1: How can successful implementation of data driven machine learning technology achieve the output growth necessary for agricultural industry to achieve food security globally?

Secondly the process of scenario building includes the category of critical uncertainties representing the possible alternation from the interaction of the projected trends and early indications (Bernstein et al. 2000, p. 56). In terms of the machine learning driven agriculture, the future of implementation points out to the systematic shortcomings of the concept. The outdoor farming represents the open system of unbenign environment containing adversarial actors and distribution shifts (Špelda and Střítecký 2021, p. 4). In accordance with the potential complications the analysis contains second research question:

RQ2: Can successful implementation of machine learning algorithms fully eradicate current obstacles to food security in agriculture?

1. Literature review

The body of academic literature supplementing the subject of the thesis is based on the compilation of varying topics of research interconnected by the core threat of food insecurity on the global scale and the attempt at remedying it. The core scholarly work used in the thesis can be based on conceptualisation divided in three categories. Firstly, the category consists of climate change and its implications on both global and local scale. Secondly, the set of articles analysing the issues of food security and agricultural sustainability, which are both closely related within and outside of the implications of climate change. Lastly a technical category of works regarding the precision agriculture and implementation of machine learning technologies in agriculture.

1.1 Climate change

Although climate change is as Wallington et al. (2009, p. 2) states a natural phenomenon, the currently observable dynamic of the process surpasses the natural dimensions by extreme means. The core of the work of Wallington et al. (2009) highlights the influence of the current industrial outputs of the greenhouse gasses on the composition of the atmosphere and its further climate aspects. The article serves as an important source of data for formation of the foundation of the construction of scenarios. The implications of the unnatural form of climate change result in emerging threats on the global stage, which are tackled in the work of Rolnick et al. (2019). The research paper includes a combination of various elements of the potential machine learning solution of the emerging threats, ranging from electricity systems to education. The core of the article not only serves as the basis for construction of a machine learning driven approach to food security through agriculture, yet primarily points out the importance of research regarding climate change.

Alternatively, the thesis includes the article by O’Neil and Oppenheimer (2002), who similarly to Wallington et al. (2009) highlight the potential dangers rising from the lack of action in response to climate change. Besides the initial dangers of ignoring the problem, the article tackles the issue of “wrong responses”, which can possibly worsen the outcome of the process. Finally, the articles by Lamb (1965), Budyko (1969) and Shine et al. (2005) supplement the main issue through validation of historical evidence of the phenomenon, astronomical perspective on the issue and inclusion of alternative measures.

1.2 Agricultural sustainability and food security

The conceptual combination of food security and agricultural sustainability builds upon the core findings provided by Schmidhuber and Tubiello (2007), who review the potential impacts of climate change on food security. The article allows for two distinct dimensions of understanding the issue. On the one hand it represents a rich source of information on the future influence of climate change, applicable for the construction of scenarios. On the other hand, the article similarly to the piece by Tilman et al. (2011) proposes a set of necessary changes to both realms of food security and sustainable agriculture. While both articles combine the core conceptual framework of climate change with the subsequent concepts of agricultural sustainability and food security, the core of the research has a limited use for the implementation of their respected core concept.

Although the overall implementation of the framework of human security remains limited to the conceptual realm of food security, the articles by Paris (2001) and Alkire (2003) serve as a groundwork for the correct integration of the concept. The work of McDonald (2010) serves as a major source for the food security framework and its dynamics. The book highlights the main working instruments including the definition and four core dimensions of the concept. In the terms of agricultural sustainability, the article by Pretty (1993) points out the basis of the contemporary push for sustainable agriculture on the records of historical perspectives and current threats plaguing the industry. In terms of the analysis the historical production growth data combined with the estimates on future necessary goals form a great foundation. Lastly, the article by Schaller (1993) points out the overlooked prioritization aspects of the concept, whilst also backing up the analysis by a set of potential alternative approaches to the current conventional system of food production.

1.3 Precision agriculture and machine learning in agriculture

The first important source for the technical component of the thesis is the piece by Gebbers and Adamchuk (2010). The article tackles the issue of food insecurity with the implementation of precision agriculture, while highlighting the need for further research of the potential remedies for the rising threat. The framework of the article aims at goals similar to the thesis, with the difference in time period and core technology, therefore building a stable platform for implementation of machine learning as the newly introduced remedy for the timeless threat. In terms of the groundwork laid by the article above, the work of Liakos et al. (2018) introduces the various implications of machine learning for the agricultural sector, serving as a source of data for the empirical part of the analysis.

In terms of precision agriculture, the analysis heavily relies on the work of Davis, Casady and Massey (1998), which introduces the historical evolution and potential future development of the concept. The article supports the groundwork laid by Gebbers and Adamchuk (2010), with clearer focus on the inner workings of the technological realm of precision agriculture. Conclusively, the paper by Cassman (1999) highlights the proposed alteration of the industry towards sustainability, while including the analysis of the contemporary use of the concept in alternative food production. The literature regarding machine learning in agriculture consists of a paper by Crane-Droesch (2018) addressing the issues of implementation of machine learning in agriculture and the impacts of climate change on the industry. In the likes of the aforementioned paper, the work of Sharma et al. (2020) and Balducci et al. (2018) represent the source of implementation framework for the analysis. Finally, the articles by Kerkech et al. (2018), McCarthy et al. (2010) and Farooq et al. (2019) supplement the analysis with empirical data in terms of contemporary research and practical use of machine learning in agriculture.

2. Conceptual and Theoretical framework

Although the issues of famine, changing environment and farming have been present through most of the human history, the theoretical implications of the factors found their way into social sciences only in the latter half of the 20th century. While the existence of food shortages and its antidote in the form of successful farming operations reached a form of scientific understanding mainly regarding farming as a natural science (Loudon 1825, p. 625-626). The theoretical underpinnings of the process itself remained limited to production enhancing research and avoided the realm of social sciences. Similarly, the issue of changing environment, present in the form of "medieval warm period" point to the historical existence of climatic changes (Lamb 1965, p. 34-36), yet both understanding of the issue and theoretical basis emerged relatively recently.

Regardless of the historical prominence in research, the phenomenon listed above influences the current world and poses a serious challenge for the future of humanity. As the causal chain connecting each of the conceptual elements of the thesis forms in logical succession, the list below follows the same logical path. Firstly, the chapter introduces the concept of climate change, followed by the potential consequence of food insecurity (within the framework of human security). The chapter is logically concluded by the conceptual remedy in the form of sustainable agricultural development (with the inclusion of conceptual realm of precision and autonomous Machine Learning driven agriculture).

2.1 Climate change

Through the Earth's history the climatic conditions were never fully stable. In light of the geological records analysed by the paleo climatologists the climate change represents a recurring part of the planet's existence. Majority of the research points towards the relative continuity of the change with major ice ages occurring in cycles of approximately 100 000 years (Wallington et al. 2009, p. 2). The cyclical nature of climate change originates from the relatively minor changes in the orientation and separation of Earth and the Sun. Three main variations influence the aforementioned changes, including tilt of the rotating axis, ellipticity of the Earth's orbit and change of the month of the closest approach, resulting in up to 10% variation of the amount of sun radiation in the arctic regions.

Although the cyclical nature of climate change might point towards a relative normality of the current situation, the context of the rate of astronomically influenced change is estimated to few tenths of a degree Celsius per thousand years (Wallington et al. 2009, p. 2-3). The current ratio at which the temperature grows surpasses the astronomical estimate by a large margin highlighting the abnormality of the situation. Besides the temperature measurements, other relevant indicators, such as retreat of mountain glaciers, lower snow coverage of the northern hemisphere, decreased extent and thickness of the Arctic ice or sea levels rise point towards the same result. Finally, as astronomers clearly point out, the current situation stems from the substitution of astronomical factors as the continuity of the three aforementioned variations (Budyko 1969, p. 618-619).

Since 1990 the Intergovernmental Panel on Climate Change uses the Global Warming Potential methodologically as a tool for estimation of the heating impact of greenhouse gases on the climate (Shine et al. 2005, p. 281-282). The result of the international use of the method resulted in the formation of the Kyoto protocol in 1992, which highlighted the influence of the greenhouse effect on the change of the climate. According to Wallington el al. (2009, p. 7-11) besides the strongest greenhouse gas, water vapor, the three strongest contributors to the greenhouse effect are Carbon dioxide, Methane and Nitrous oxide. Although water vapor has the strongest effect, the amount of water in the atmosphere is not strongly influenced by human activity. The remaining three gases compensate for the lower greenhouse effect by the sheer quantity of their output into the atmosphere by human activities. Finally, the water vapor increases in response to the rising temperature, as the rest of greenhouse gases increase the evaporation through the increased heat (Wallington et al. 2009, p. 7).

The emerging danger of climate change confronts the contemporary social and economic system through a variety of factors. An increase in yearly average temperature by approximately 1.5 degree Celsius annually endangers not only the so-called indicators in form of coral reefs, but also the crops that ensure the food supply for the majority of humanity (Schmidhuber and Tubiello 2007, p. 19704-19705). Most climate prediction models contribute the increasing volatility and extremity in weather to climate change, therefore indirectly pointing to the major threat to current agriculture. Besides the realm of volatility, the global warming endangers the availability of fresh water (Wallington et al. 2009, p. 7), which remains vital for both living conditions and farming in certain parts of the world.

To conclude, the conceptual framework of climate change based on the output of the greenhouse gases by industries highlights the immense importance of environmental threats present in the near future. Despite the action of international organizations, such as the United Nations in form of the United Nations Framework Convention on Climate Change, the phenomenon of global warming remains active. Although documents in the likes of Kyoto protocol and Paris agreement aim at reduction of the sources of greenhouse gases, the current situation validates the dangerous trend and its consequences (O'Neil and Oppenheimer 2002, p. 1971). The dangers produced through the continuation of the greenhouse gas output to the atmosphere do not only contain critical damage to natural ecosystems, yet simultaneously to humanity through disruption of agrocenosis. The estimated influence of the aforementioned factors points towards a proliferation of food shortages and possible elimination of agriculture in selected regions on basis of weather volatility and droughts (Schmidhuber and Tubiello 2007, p. 19708).

2.2 Food (in)security

During the final stage of the Cold War security scholars started abandoning the original vision of purely state-centric military focus of the discipline with the emergence of the concept of Human security (Alkire 2003, p. 13-14). The concept of human security builds upon the notion of prioritization of the individual security needs of individuals. Communities, groups, or nations in perspective of human security build their security priorities on the basis of the individual members welfare (Paris 2001, p. 87). With the end of the clash of superpowers the importance of human security arose, as the lack of major ideological conflicts heralded the proliferation of internal struggles. The rise of postcolonial and civil wars not only lured researchers into exploration of new variables, but also highlighted the importance of basic human needs over the withering essence of ideological understanding.

With the security scholars focusing on exploration of the human security framework in cases of fresh internal conflict, the deepening and complexion of uncovered phenomenon led to the emergence of new concepts based on the core framework. Among the newly emergent concepts of human security the food security or alternatively food insecurity rose into prominence (McDonald 2012, p. 4-5). Basis of the concept consists of the four main dimensions to the Food and Agriculture Organization of the United Nations (FAO) definition: ‘‘situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life’’ (McDonald 2012, p. 15).

The availability of the food, as the first dimension heavily relies on the agricultural industry and its capabilities to produce sufficiently in response to the demands of the population. Secondly, the dimension of stability builds on the basis of the existence of stable food supply for each individual member of society, regardless of external factors such as seasonality of economy. Thirdly, access of food with the core elements of purchasing power of individuals transcending the boundaries of monetary means. Fourth main dimension of food security conceptualization is quality and reliable storage of food. The dimension to a certain extent encompasses the concept of health security in terms of the health aspects of quality and safety of food on the welfare of the consumers (Schmidhuber and Tubiello 2007, p. 19703).

While utilization of food in terms of the latter two dimensions contains great potential for use of the implementation of machine learning technology the conceptual core of the analysis builds on the framework of the first two dimensions. The availability and stability of food supply represent the core elements of the aforementioned influence of climate change on the capacity of the agricultural industry to fulfil its role. Although the option of limited conceptual basis restricts the potential scope of the scenario, the relative lack of connection between the other components of the conceptual framework supports such choice. To conclude, the implications of the conceptual framework of the two selected dimensions of food security serves as the basis for implementation of specialised agricultural concepts.

2.3 Agricultural sustainability

The idea of agricultural sustainability remained relevant throughout history since its oldest recorded instances in Chinese and Greek texts (Pretty 2008, p. 447). The historical implications of the concept highlight the currently less relevant issues of undeveloped land, lack of effective crops and relatively extreme seasonality of outputs. Although the historical form of the concept might lack relevance in the current world, the modern alteration born in the late 1950s builds on the core aspects of the ability of the agricultural industry to meet the demands of the population. The connection between the two alterations remains limited in the core goal, as unlike the historical production perspective, the outputs of the global agricultural industry rose by staggering 145% since the 1960s (Pretty 2008, p. 447).

Despite the immense improvements of the overall output of the industry, a set of overlooked issues gained prominence, leading to the transformation of the concept to its modern form. According to Pretty (2008, p. 447) the core of the modern concept of agricultural sustainability stands on the goal of development of agricultural technologies and practices with three main characteristics. Firstly, the practices and technologies should lack any adverse effects on the environment and all its dynamics. Secondly, such tools should be easily accessible and economically effective for farmers. Finally, the results of the implementation should lead to improvements in food productivity and have measurable beneficial side effects on environmental goods and services. The concept itself incorporates economic, social, and environmental aspects, while enhancing both resilience and persistence of the agricultural sphere.

The core issues with contemporary conventional farming can be described as the “hidden costs” of the industrialization of the agricultural industry, which have been broadly accepted as justified in response to the staggering rise of production (Schaller 1993, p. 90). With the current focus on the “hidden costs”, the list of manifesting issues includes the contamination of water by agricultural chemicals and fertilizer sediments, combined with the disruption of the quality of agricultural products by pesticide and feed additive residuals. The list continues through loss of genetic and environmental diversity and growing pest resistance to pesticides. The concluding aspects incorporate over reliance on non-renewable resources, immense erosion and contamination of soil and destruction of wildlife habitats including the beneficial insects and predators (Schaller 1993, p. 90-92).

While the underlying criticism of the concept highlights a plethora of often overlooked issues accompanying the agricultural industry, the core elements of agricultural sustainability remain in the realm of formation of alternatives. How can this alternative approach be defined? On one hand the current academic perspective allows for the simple characteristics of a system that aims to make the best possible use of environmental goods and services while not damaging or altering these natural assets (Pretty 2008, p. 451). Such definition contains conceptual approaches such as biodynamic, organic, extensive, or ecological farming. While the debate on which of the aforementioned stances allows for the highest possible sustainability remains unsolved, the comparison with conventional farming highlights all the alternatives (Schaller 1993, p. 91-92).

To conclude, the core of the concept builds on the historical push for a self-sustainable food source, while the modern alteration focuses on the contemporary issues plaguing the environment of the agricultural industry. The inclusion of a varying set of alternative approaches allows for an innovative perspective on the resolution of the aforementioned "hidden price" of the production. Finally, the threat of the need for 70-110% increase in output to compensate for the rising population forces the concept to reform on the basis of search for a balanced approach capable of resolving population needs as well as the long-term sustainability of the system (Pretty 2008, p. 447-448). Although the implementation of machine learning as a potential dimension of agricultural sustainability remains a relatively overlooked topic, inclusion of such innovative conceptual frameworks can bring development to the issue.

2.4 Precision agriculture

Precision agriculture, or alternatively the information driven management of agricultural production systems began to emerge during the 1980s. The concept was often defined by the leading technologies enabling its existence; thus, it was often referred to as GPS (Ground Positioning System) agriculture (Davis, Casady and Massey 1998, p. 1). As the alternative name suggests the core aspect of the concept stands on the realization of the importance of the key information for successful production of agricultural goods. The initial understanding of the variable environment and factors affecting the farming process can be traced back to the ancient texts regarding agricultural sustainability (Pretty 2008, p. 447). Although the knowledge of variation between production units was present throughout the history of agriculture, only the second half of the 20th century highlighted the potential for distinction between variation in fields and variation within the fields themselves.

Increasing awareness of the variation between sections of fields in crop and soil conditions, combined with the progress of technology lead to the implementation of systems such as GPS or geographic information systems (GISs). The initial goal of the implementation consisted of adaptation of fertilized distribution in terms of varying soil conditions (Gebbers and Adamchuk 2010, p. 828). Currently, the concept encompasses a plethora of added technologies including crop scouting, remote sensing, yield mapping and automatic guidance of agricultural vehicles (Davis, Casady and Massey 1998, p. 2-4). Despite the varying fields of use, Gebbers and Adamchuk (2010, p. 828-829) argue that the core elements of the concept remain threefold. Firstly, the correct optimization of all the available resources with the main goal of increased financial profitability and sustainability of agricultural operations. Secondly, the reduction of negative environmental impact, through the limitation of necessary inputs. Finally, the improvement of the work environment, its conditions, and social aspects.

Although the contemporary form of the concept remains heavily reliant on the use of GPS, or alternatively Galileo network, the near future indicates a deeper delve into the variations within the field to the extent of individual crop plants (Davis, Casady and Massey 1998, p. 2-4). The push for incorporation of secondary and tertiary sets of data to the working environment of the concept lead to a steady increase in the global prominence of its use. Besides the conventional realm the concept re-emerged under ecological agriculture, with immense focus on reduction of necessary production operations responsible for the disruption of agrocenosis (Cassman 1999, p. 5957-5958). Inclusion of variable farming practices in the practical use of the conceptual framework highlights the future potential for the development of new applications and inclusion of technologies.

To conclude, the concept is designed around the implementation of technologies with the aspiration of data collection, interpretation, and application. The operationalization of the concept on the terms of further development of the agricultural industry allows for a relatively flexible approach to inclusion of new technologies, as the aforementioned variability in agrocenosis remains layered. The incorporation of machine learning technologies poses in light of the historical development of the concept a realistic outcome, besides the current research and limited practical use of the technology within the agricultural sector. Finally, the concept of precision agriculture does to some extent include autonomous technologies which make it the closest concept to implementation of machine learning in the industry (Gebbers and Adamchuk 2010, p. 830). Yet it is important to highlight the state of autonomous agriculture, as most contemporary technologies remain within the realm of “human in the loop” or potentially “human on the loop” levels of automation.

2.5 Machine learning

Machine learning is a discipline focused on the construction of a computer system capable of automatic improvement through interpretation of experience. The core algorithm of the machine learning process is "trained" to find patterns or unique features within large sets of data. In artificial intelligence, the concept emerged as the prominent tool for development of practically used software (Jordan and Mitchell 2015, p. 255-256). Generally, the approach of training the algorithm on the basis of desired outcomes performs superiorly to manual programming of responses for all possible inputs, which used to be prioritized throughout computer science for the majority of tasks. Through consumer services, the diagnosis of faults in complex systems, and the control of logistics chains the implementation of machine learning algorithms proved its value (Jordan and Mitchell 2015, p. 255).

The core theoretical elements of the concept can be traced back to the 1950's, although the initial use of the framework remained within the realm of statistics unlike the contemporary digital form. Although the so-called "AI winter" period of the 1970's halted the progress of machine learning research right after the introduction of Bayesian methods, the most important discoveries responsible for the current proliferation of implementations happened during the 1990's. The period introduced use of large datasets, immense computational power, and the conceptual formation of deep learning neural networks, which emerged as the future of scalable machine learning systems (Miikkulainen et al. 2019, p. 293). With the inclusion of the rapid increase in computational power during the beginning of the new millennium, deep learning neural networks became the main tool in computer vision, speech recognition and a plethora of other areas. Currently the framework of deep learning serves as both state of art tool and basis for further development of machine learning.

3. Methodology

The ultimate goal of predicting the future transcends across all scientific fields, from physics to international relations. As famous Danish physicist Niels Bohr allegedly pointed that: “Prediction is very difficult, especially about the future.”, he reminded the scientific community of its inability to accomplish such a feat (Ditrych et al. 2012, p. 93). Although the obsession with prophecies can be traced back to the ancient civilizations of Mesopotamia or Antiquity, the idea of learning from the future entered the field of science with the “New Scenario Building” methodology. With the goal of exploration of potential outcomes of reality, the core aspiration of scenario building shifted from attempts at uncovering the future to analysis of its aspects and their interpretation in current issues (Bernstein et al. 2000, p. 53-55). As the issues of future implications of the climate change on food security and the potential solutions for them are outside the scope of contemporary knowledge, the potential of exploration of the scenarios of the future can serve as a great source of lessons for current researchers.

3.1 The new scenario building

The new scenario building technique builds upon the relatively surprising inspiration in evolution biology which despite minor discrepancies represents a working open system, similar to the one analysed in the international relations. The core of this inspiration stems from the opposition to Newtonian determinism, which can be compared to the contemporary realm of theories of International relations. The scenario building builds its alternative approach on the concept of forward tracking or forward reasoning, which represents the idea of a transformed method of process tracking. The transformation of process tracking works with the alternation of analysed timeframe from past to the future (Ditrych et al. 2012, p. 99). This form of “forward process tracking” does not aim at a perfect projection of the future, but rather attempts to produce a viable set of scenarios, which in larger numbers point towards the most probable outcomes of contemporary existence.

According to (Bernstein et al. 2000, p. 55) the methodology itself works on the basis of seven main steps of the process which start with the identification of the driving forces, followed by the specification of predetermined elements. The process continues with the identification of critical uncertainties, development of “clear plot lines” scenarios, extraction of early indicators for each scenario. Concluding parts of the scenario building consists of consideration of the implications of each scenario and development of the so called “wild cards” which are not integral parts of any of the scenarios, yet represent a potential factor influencing the open system.

Driving forces represent the causal elements of the analysed issue, including the change of climate and depletion of resources. Although not limited to, a great number of cases stems from causal arguments of major social science theories (Bernstein et al. 2000, p. 55). The thesis operates a framework of human security through the implementation of food insecurity concept. In regular process tracking the causal arguments serve as the independent variables for explanation of the analysed trend, whereas in terms of scenario building their role represents the starting point for potential futures. Most of the constructed futures contain a similar set of food security issues structured around population growth, depletion of natural resources and negative implications of changing climate. The set of driving forces threatening the humanity in potential futures faces a differing set of countermeasures including automation of agriculture and sustainable farming. Unlike process tracking the methodology of scenario building requires a larger set of driving forces (Ditrych et al. 2012, p. 100), which are after successful identification used for recombination and formation of diverse causal chains resulting in multitude of potential scenarios. The two opposing sets of driving forces in the analysis consist of manmade climate change, food (in)security, sustainable farming, automation of agriculture and the subsequent set of concepts within their framework.

Predetermined elements form the relatively certain parameters relevant for the whole constructed scenario, thus including factors such as the climate change, depletion of natural resources and population growth. The factor of relative certainty poses a great challenge as the certainty of the predetermined elements builds on subjectivity and motivated thinking, which greatly harm the objective outcome of the analysis. The recommended set of factors used for the role consists of slowly changing phenomena such as demographics, geography, and physical resources (Bernstein et al. 2000, p. 55). In certain cases, the choice of such weakly altered elements does not ensure their relevance for the scenario, as major disasters, conflicts, economic downturns, or invention of revolutionary technologies possess the power to do so. In respect of the recommendations the analysis implements global climate warming, population growth and depletion of natural resources (incl. water, fertile soil, and fertilizers) in majority of scenarios. Chapter 4 (data) represents the set of predetermined elements of the analysed case while also highlighting their implications in the contemporary world.

Critical uncertainties, the broad category of deterministic elements, which form on unpredictable interactions between the predetermined elements, which can produce events of unknown magnitude and consequences (Bernstein et al. 2000, p. 56). The range of critical uncertainties contains implications of newly increased production capabilities of colder regions, catastrophic lack of practical adaptation capabilities for autonomous agricultural vehicles or major decrease in population growth on basis of dwindling food supply. The critical uncertainties represent the core of analysis of a broad set of scenarios, as their inclusion in the construction highlights the volatility of unpredictable combinations of driving forces in an environment of amalgamated predetermined elements. As the validity of critical uncertainties increases only with addition of empirical data its proposition suffers heavily from uncertainties, yet in most probable terms the set of critical uncertainties of the analysis contains adversarial actors, turbulence of climatic factors and lack of technological adaptation. The uncovering of critical uncertainties represents the core of the fifth chapter focused on projection of the variable elements of the scenarios.

A *scenario plot line* represents the overall story of how each scenario unfolds. The core of plot lines lies in the description of plausible behaviour and interaction of driving forces, critical uncertainties, and predetermined elements in each proposed scenario (Ditrych et al. 2012, p. 100). A plot line follows its own logical path to fruition which relies on both theoretical elements and their unconventional counterparts. The analysis mainly builds upon the most plausible plot line of further depletion of natural resources and volatilization of climatic conditions, followed by decreased stability of food security on the global scale. The plot lines vary in the countering measures as well as in critical uncertainties represented by the extent of actual implementation of machine learning solutions or growth of production in underdeveloped regions. Whereas in conventional theories the multifinality of outcomes complicates the analysis, in case of a scenario building the creation of a set of possible scenarios poses an advantage as it allows for broader exploration of the potential future. On basis of continuity to the critical uncertainties the scenario plot lines are prominent aspect of the initial part of the seventh chapter of the thesis which lays the groundwork for construction of scenarios.

Early indicators are defined as the contemporarily observable and measurable aspects of the proposed scenarios, such as the data highlighting the changing climate or practical use of machine learning technology in agriculture. Through transformed process tracing the methodology aims at differentiation and validation of each perceived scenario through inclusion of a larger set of variables to the analysis. The inclusion of increased sets of data the scenario building methodology avoids influence of post-hoc determinism, thus further confronting the historical contingency (Bernstein et al. 2000, p. 57). Additionally, with the further implication of uncovered trends, the elements identified can in terms of sufficient continuity transform into predetermined elements of the latter parts of the scenario. The identification of the early indicators occupies the latter half of the fourth chapter of the thesis, therefore completing the set of contemporary data with the predetermined elements. The data used for the analysis consists of climate change reports, papers on global and localised food insecurity and contemporary research in agricultural sustainability and automation.

Implications of scenarios aim at understanding the consequences of the causal chains present in each scenario with the focus on decision making and behaviour of actors. The goal of implementing the implications of scenarios lies in the realm of evaluation of possible influence of the decision makers on the fruition of the scenarios on basis of their reaction to the early indicators. With the inclusion of the implications, the potential for drastic changes to scenarios arises (to the extent of scenario non-fruition), but overall validity of the explored plot lines increases (Ditrych et al. 2012, p. 101). The thesis aims at both interpretation of outcomes in the realm of policy makers, and the overall society as with radical decrease in quality of life and stability of food supply the reliance on decision makers in terms of completion of scenario plot line diminishes. As the core element of the formation of scenario outcomes, the implications of scenarios complete the groundwork laid in the beginning of the sixth chapter by the scenario plot lines.

Wild cards can be defined as low probability events, actions or situations capable of radically altering or dismantling the causal chain of scenario. As Bernstein et al. (2000, p. 58) states, the wild cards include assassinations of policy makers, natural disasters, dramatic economic changes, internal conflict and famines. A set of wild cards can represent extreme values in known independent variables, yet others stand for values outside of the proposed set of causal arguments. The use of wild cards in terms of technology and climate change represent a strong source of potential extreme values. But in respect to the globality of the phenomenon the potential for influence outside of the predetermined elements and driving forces highlights a rich source of unknown extremes. Although then wild cards represent a varying and unstable force within the realm of scenarios, they remain core element of the sixth chapter.

To conclude, the methodology of scenario building aims at the exploration of potential future and interpretation of the acquired lessons through formation of causal chains driven through a set of variables and individual plot lines. The core distinction between variables stems from the certainty, value and driving forces, forming the three basic components of the process. The combination of the aforementioned variables formed in terms of its respected plot line shapes the basis of a scenario. The inclusion of early indicators and implications of scenario complete the context and overall plausibility of the individual scenario, whereas the factor of wild cards ensures the complete simulation of open system dynamics. The outcome of the applied methodological approach consists of three scenarios chosen on the basis of probability. Although exploration of all possible scenarios offers broader opportunities for lessons learned, the relative limitations of the thesis point towards a more restricted and disciplined approach. The three concluding cases consist of two plausible scenarios (chosen on basis of early indicators) and one “black swan” oriented scenario representing the unpredictability of open system dynamics of the social sphere.

4. Data

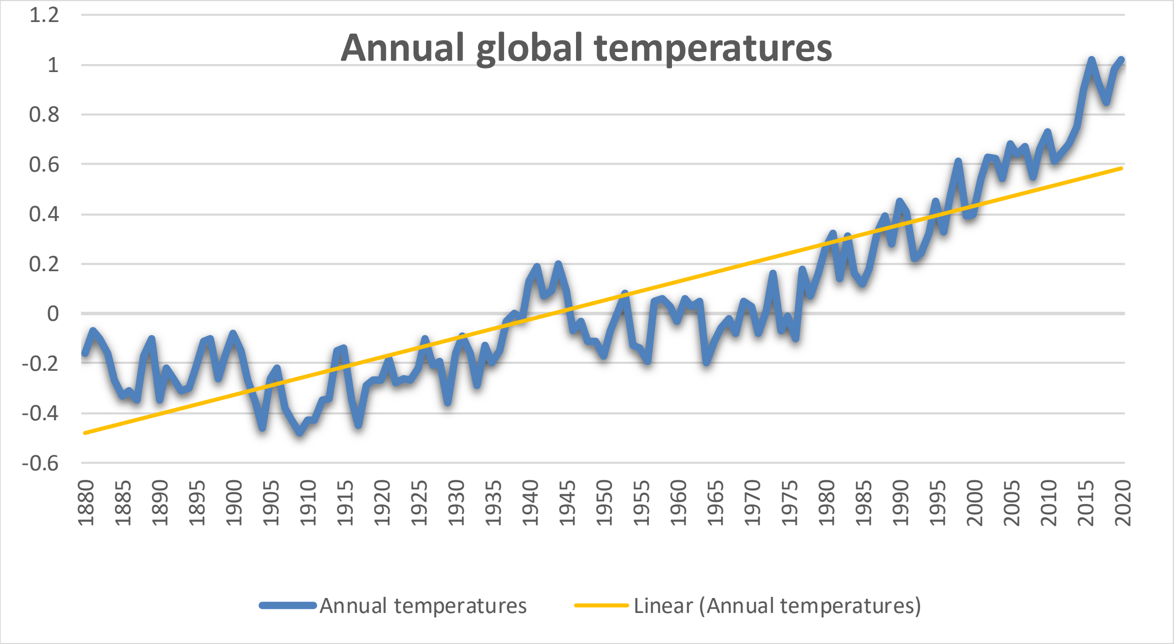
4.1 Stable elements

The word as we know it remains a relatively unpredictable environment, as not only humanity lacks full explanation for a great number of natural processes, but more importantly possesses no means of reliable prediction of the future development (Bernstein et al. 2000, p. 55). Although the future remains largely unknown and outside of our knowledge a relatively broad category of phenomenon can be to a certain extent predicted. Bernstein et al. (2000, p. 55-56) defines the" predetermined elements" category as a variable that experiences relatively minor and slow changes over long periods of time. The importance of relativity remains relevant for the category, as its definition calls for quite strong subjectivity, as thanks to "wild cards" no phenomenon musters full resistance to turbulent changes. In terms of the analysed issue and the subsequent instability of the global environment the choice of such elements presents a challenge, yet in light of the available historical data global warming, population growth and depletion of natural resources emerged as the most probable predetermined elements.

4.1.1 Climatic data

Outside of the conceptual framework of climate change, or alternatively the global warming, the climatographic research including both Paleogenic and anthropogenic datasets presents a reliable source of perspectives on the contemporary situation. In terms of the recorded observations Parry et al. (2007, p. 4) highlight the unprecedented change of yearly temperatures on global scale within the period of 35 years (1970 - 2004). The data presented in the paper point out a 0.5-to-2-degree Celsius increase in annual sum of temperature in the vast majority of the globe, with areas such as Alaska experiencing 3.5 degrees increase. Although the presented increase alone might seem relatively minor, the situation changes in context of natural solar temperature variation (a few tenths of degree Celsius per thousand years) and the benchmark of indicator organisms (1.5 degree Celsius being the danger line) (Wallington et al. 2009, p. 2-3, 9).

Perspective of thirty years of data poses a fairly limited basis for long term reliance of predictions, therefore the inclusion of the global climate monitoring data ranging from 1880's to the beginning of 2021 reinforces the reliability of predictions (see Graph 1). Overall, the data gathered through the period point out the annual temperature growth by approximately 0.1 degree Celsius per decade (NOAA 2021). Alternatively, as Wallington et al. (2009, p. 3) points out, according to the paleoclimatic research of ice cores, wood structure and soil analysis the annual temperature of the northern hemisphere remained relatively constant in between negative 0.5 and zero degrees Celsius. It is important to note that most records predating the 1950's remain to a certain extent uncertain largely thanks to lack of global coverage and a stable precision of measurements. Secondly, the data predating 1860's represents a combination of proxy indicators forming a reconstruction, therefore maintaining limited reliability (Wallington 2009, p. 3).

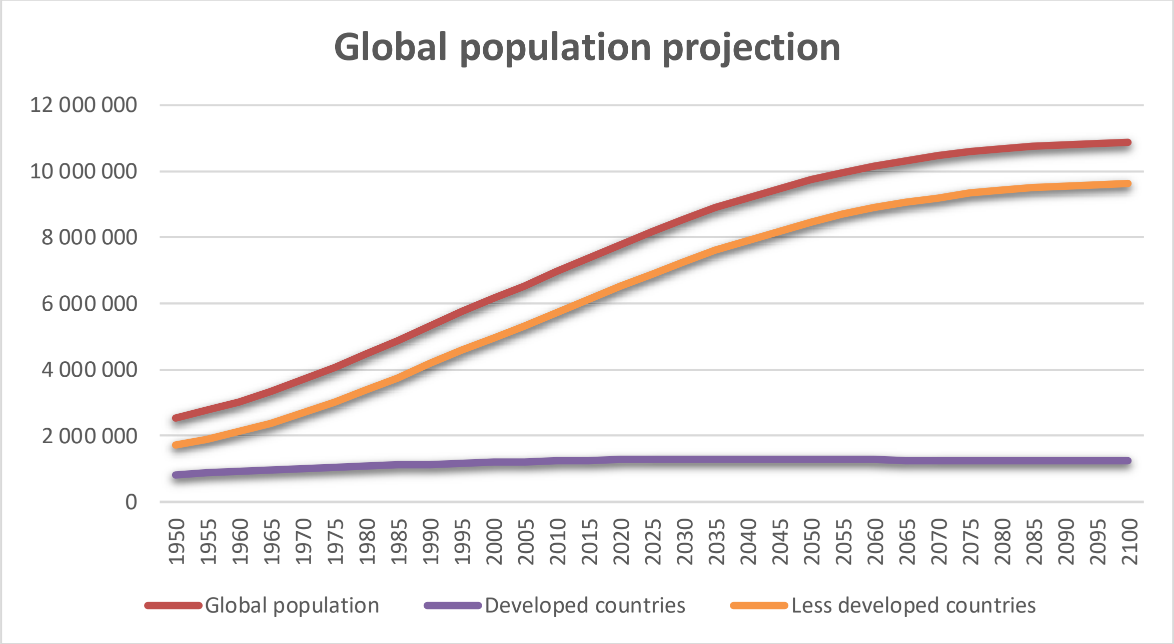


Graph 1 – Annual global temperature measures (data via NASA 2021)

Finally, although the recent development of the climate might resemble an unprecedented irregularity in the normal process, the context of the situation points towards a trend (See Graph 1). Majority of research on climate change equates the climatic irregularities with the rising industrialization of human production, which is in turn responsible for the immense outputs of the so-called greenhouse gasses (O'Neil and Oppenheimer 2002, p. 1971). The results of aforementioned research of relation between climate and greenhouse gases encouraged both public authorities and international organizations to the creation of agreements and campaigns calling for reduction of industrial emissions. The numerous attempts at reduction of global warming and their limited success in places such as European Union (Bayer and Aklin 2020, p. 8809-8810) remain ineffective in context of global emission growth. The growth that stems from the contemporary phenomenon, such as consumerism, prioritization of economics and the globalization of markets and industries.

4.1.2 Population growth

Even though the history of humankind was plagued by frequent wars, pandemics, and natural disasters responsible for immense loss of lives, the population always healed and increased. The major driving forces of population growth included food and health security aspects (Blacker 1947, p. 88). The population growth accelerated through events such as Neolithic revolution, invention of four field crop rotation (Loudon 1825, p. 630-635), industrial revolution or the introduction of handwashing in obstetrics by Ignaz Semmelweis (Best and Neuhauser 2004, p. 233). While the majority of the inventions and revolutions remained relatively regional, the globalizing factor of colonialism heralded the expansion of the worldwide population growth. The aforementioned accelerating forces resulted in the century and a half of unprecedented global population growth resulting in the 7 billion benchmark in 2011 (see Graph 2). In terms of the contemporary projections, the result of two centuries of immense population growth can result in tenfold increase in the global population by 2100 (Ezeh, Bongaarts and Mberu 2012, p. 142).



Graph 2 - Population growth development and projection (data via UN 2019)

Majority of estimates highlight the possibility of further rapid population growth by approximately 2% in the underdeveloped countries. The populations of the third world regions possess a greater fertility rate, in comparison to the transatlantic region as well as east Asia (Ezeh, Bongaarts and Mberu 2012, p. 142). In terms of the probability of the potential development of the fertile communities a robust framework based on a set of three components of population change as well as supplementary inner elements. Population change is in terms of the framework formed on a combination of future fertility, mortality, and migration trends, which in their uncertainty and factors such as sex specific age patterns present the boundaries of future projections (Lutz and KC 2010, p. 2783). Generally, the projections tend to be adjusted in cycles of 5 years, which represent a time period long enough to manifest irregularities in the major population changing components.

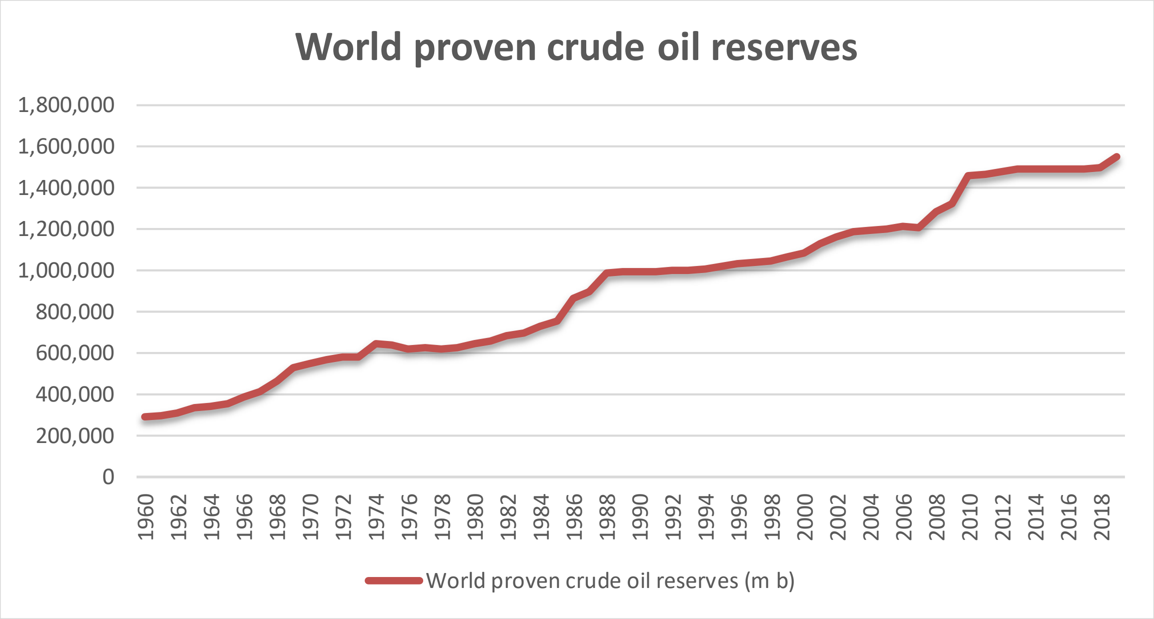
With the relative uncertainty and use of projections for the population figures predating 1950's, the analysis mostly focuses on the data available from the United Nations Department of Economic and Social Affairs 2019 paper. Although the majority of the projections predict a peaking of the population close to the year 2100 (see Graph 2), the limiting factor of continuous growth stems from the probabilistic approach towards the top limit of potential life expectancy at 120 years (Lutz and KC 2010, p. 2784-2785). Despite the limiting factors on both sides of the timeline, the United Nations Population prospects remain the main source of both empirical data and projections of future development for the analysis. Likewise, to the perspective on global stage, the analysis focuses on identical dataset in terms of both projection and assessment of regional characteristics as contemporary population growth and future fertility centres around Africa, South Asia, and South America (Ezeh, Bongaarts and Mberu 2012, p. 144).

4.1.3 Depletion of resources

The depletion of resources remains among the major future threats to humanity thanks to the over reliance on non-renewable resources in most industries. In the agricultural sector the issue consists of multiple elements, including depletion of fertile soil and fossil fuels. Firstly, despite its globality the phenomenon of fertile soil depletion manifests with extreme regionality. In the case of the European Union, where the intensification of agriculture resulted in decrease in overall farmland due to its inapplicability for modern agricultural practises (Rabbinge and Van Diepen 2000, p. 89-91). The major threat for the currently used soil stem from the combination of climate change and inadequate tilling techniques resulting in erosion and washing of the nutrients from the soil. Alternatively, in case of the Americas the major threat to the currently used farmland remains within the realm of unnecessary overfertilization (Fulford and Culman 2018, p. 63-64) and contamination with residuals (Hitch and Day 1992, p. 263).

In terms of the less developed parts of the world, the soil not only faces contamination and erosion, yet more importantly a nutrient depletion, thanks to the overcultivation and tropical deforestation (Tan, Lal and Weibe 2005, p. 128). As data suggests, the contemporary depletion of nutrients in regions such as Sub-Saharan Africa with losses up to 22 kg of nitrogen, 2.5 kg phosphorus and 15 kg potassium (Sanchez 2002, p. 2019), points out a major issue for the stabilization of the food supply in the region. In terms of the projection and analysis of the phenomenon, the thesis uses datasets available from Global Soil Information System (GloSIS), which highlight the global emergence of fertile soil depletion (Omuto et al. 2013, p. 60-64).

Although the farmland and its fertility remain the core of the agricultural production chain, the contemporary reliance of the industry on the energy from fossil fuels poses a threat to its stability. As Pfeiffer (2006, p. 3-4) highlights, the contemporary food production systems in the developed world use approximately 1000 litres of oil per acre of farmed land. The overall use of oil in agriculture splits mainly between the production of inorganic fertilizers, operation of field machinery, irrigation, and transportation. In light of the issue of nutrient depletion mentioned above, the reliance of the fertilizer production on fossil fuel energy points towards an inevitable limit for future development. The reliance of irreplaceable elements of the food production system on oil in combination with estimates pointing towards possible depletion of the global reserves in approximately 40 years highlight an emerging threat (Shaffie and Topal 2009, p. 187-188).



Graph 3 – World proven crude oil reserves (data via OPEC 2020)

Despite the constant increase in global oil reserves (see Graph 3), the period of potential depletion should most likely remain stable due to the extent of current exploration (Shaffie and Topal 2009, p. 181-182). The daily demand increased from 21 000 barrels per day to nearly 100 000 in six decades (OPEC 2020), thus highlighting the reliance of current civilization on oil energy. With up to 17 % of the energy used in the US accounted for in Agricultural use (Pfeiffer 2006, p. 3), and the rest of the world following in the same direction, the statistics mentioned above remain bound to continually rise. Although the potential remedy for fertilizer production and field machinery can be seen in the technological shift towards renewable electric energy, the contemporary situation proves such a strategic shift practically impossible in a short period of time. Finally, the depletion of oil reserves represents only a part of the problematic reliance of current agriculture on non-renewable resources, as the majority of inorganic fertilizers originate from depleting minerals (Bardi EL Asmar and Lavacchi 2013, p. 228-230).

4.2 Contemporary indications

The uncertainty of the future remains the core element of the scenario building, yet the inclusion of phenomena indicating potential future development solidifies the empirical component. In light of the stable elements constructing the basis of the scenario, the set of early indicators both proposes a stable platform for a category of currently absent processes, as well as a steppingstone for the incorporation of the process into the future set of predetermined elements (Bernstein et al. 2000, p. 57). While indication never assures a fruition of the projected process, thanks to the unpredictability of the future highlighted throughout the thesis, the combination of stable empirical data and indicating elements of the current world stabilize the boundaries of the scenarios. With the core emerging elements of the constructed scenarios including global warming driven food insecurity and subsequent machine learning countermeasures, the analysis focuses on the contemporary occurrences of the phenomenon.

4.2.1 Climate driven food shortage

The contemporary situation in Sub-Saharan Africa can to a certain extent represent the future threats emerging with the global warming effects on local climate, as it remains the region with the highest reliance on seasonal weather (Ringer et al. 2010, p. 14). Not only does the region face unparalleled food shortages on basis of agricultural industry underdevelopment and overall lack of proactive approach by the governments, yet as plethora of studies suggests the strongest influence of climate change on the environment (Wheeler and Von Braun 2013, p. 511-512). The emergence of this regional factor only highlights the projected results, which predict up to 30 % reduction to the current limited yields by 2050 (Ringer et al. 2010, p. 10-11). The set of factors highlighting the aforementioned situation contains a combination of meteorological and ecological elements, which in turn solidify the complexity of the issue and a lack of robust countermeasure.

Probably the most disastrous element of the process stems from the combination of deforestation and the subsequent desertification. Dynamic desertification of the region remains to a large extent unopposed thanks to the enormous destruction of vegetation coverage, thanks to which the region leads the list of locations with highest rates of deforestation (Diarrassouba and Boubacar 2009, p. 9-10). With the driving force of deforestation residing in the combination of activities of the small-scale farmers who represent the majority of the regional workforce (Rudel 2013, p. 5-6) and the rising volatility of seasonal weather, the potential for change remains limited. Besides the core danger of desertification, the process of deforestation in the region results in further erosion of soil, thus increasing the amount of nutrients lost and lowering the overall yields. Besides the two aforementioned elements, the disruption of wet and dry weather cycles not only results in the increased rate at which both desertification and erosion of soil continue, yet more importantly in the increased occurrence of droughts and floods (Hastenrath et al. 2010, p. 817).

The most visible manifestations of the climate change process in the sub-Saharan region include the increase in droughts and floods highlighted above, and the rising number of locust swarms. Firstly, the combination of unpredictable occurrence of weather extremes not only endangers the yield of crops on fields, but more importantly disrupts the soil structure. Soil regularly exposed to radical changes of weather in form of droughts and floods is extremely endangered to erosion, and landslides which greatly disrupt the fertility of soil, its water holding capacity and the overall agricultural usability of the fields (Trnka et al. 2016, p. 239, 247). Finally, the increased rate of locust swarms plaguing the region can be clearly contributed to two main factors, both connected to climate change. The loss of biodiversity, which results in lack of natural predators responsible for mitigation of locust populations and the rise of temperature connected with disrupted wind and rain patterns, which help their population growth (Salih at al. 2020, p. 584).

To conclude, the environment created by the influence of the factors listed above results in a rise of food insecurity throughout the region. Although the majority of the factors remain strongly influenced by the climate change and the various implications of the process, the role of local governments and enterprises in the food security dynamics only highlights the scale of the situation. The current reliance on imported food is projected to massively increase in the upcoming decades thanks to the climate change elements listed above (Ringer et al. 2010, p. 16-18). Finally, in terms of agroecological measures in yields and the availability of imports the situation in the region remains mostly "Alarming" in terms of the Global Hunger Index, thus highlighting the extent to which the development of food insecurity in the region can result (Wheeler and Von Braun 2013, p. 509).

4.2.2 Machine learning in agricultural industry

It is widely accepted that the agricultural sector faces a complex issue with the development and implementation of new technologies. The unwillingness of both public authorities and the private sector to invest in innovations can be somewhat influenced by the strongly conservative mentality of the industry itself and the problematic process of adoption of new technologies by farmers (Guerin and Guerin 1994, p. 568-569). In spite of the aforementioned altitude, a plethora of academic institutions and non-governmental organizations work on the development of new technologies, making the automation of agriculture potentially realistic. Among the core aspects of the contemporary research, the combination of computer vision (McCarthy et al. 2010, p. 13-14) and big data analysis (Balducci, Impedovo and Pirlo 2018, p. 1-3). A majority of the research differentiates on the location of production, as both currently developed uses of machine learning can serve both indoors and outdoors production facilities, which contain differing threats and challenges.

The indoor environment of greenhouses serves as the ideal space for implementation of new technologies thanks to its properties of controlled environment. Most large contemporary greenhouses use autonomous controlling systems for temperature, humidity, and watering, while using multi factor sensors positioned through the building (Mohanty and Patil 2013, p. 17). The further development of the computer-controlled elements of greenhouse farming is set to continue developing in terms of use of machine learning for further decrease of necessary human interaction with the sensor outputs, possibly resulting in full automation. While big data analysis is currently practically applied, the implementation of computer vision models for indoors use remains uncertain. Despite the lack of critical issues such as differing sunlight reflection (McCarthy et al. 2010, p. 2-3), the successful incorporation of computer vision in terms of autonomous tools capable of fertilizer application or weed detection remains limited to further research (Osadcuks et al. 2014, p. 955-956).

Alternatively, the outdoors represents a much more complicated environment for the application of computer vision. Majority of practical testing on outside fields highlighted the main adversarial aspects in terrain, day cycle and positioning of the sun, which all combined disrupt the successful application of computer vision (McCarthy et al. 2010, p. 13-14). Currently the research and field trials focus on three main realms of visual data processing. Yield prediction, disease detection and weed detection (Liakos et al. 2018, p. 7-14), which all together represent the core of both conventional and ecological farming. In terms of big data analysis, the outside realm of farming relatively follows the greenhouse industry, as despite more complicated data gathering, the need for the procession dwarfs that of controlled environments. Prior to the first application of machine learning, the whole agronomic process relied on calculations of human analytic, who was since the beginning of the new millennia often supported by calculation software. The contemporary situation both allows for practical use of limited amounts of machine learning systems, yet more importantly highlights the near future implications of the technology on the agronomic systems (Balducci, Impedovo and Pirlo 2018, p. 18-19).

Overall, the contemporary state of machine learning implementation in agricultural industry remains relatively limited, yet as the multitude of research projects highlight, the implications for the near future are plentiful. In terms of the two distinct realms of use, the outdoors and indoors, the development points towards a relatively much closer incorporation of machine learning systems into the main production processes. Alternatively, the outdoors use of both computer vision and big data analysis faces a plethora of difficulties, which slow the progress of technology. Yet the overall trend of the use of machine learning in agriculture remains rising in both relevance and importance. Generally, contemporary research should result in small scale practical applications within the next decade (Sharma et al. 2020, p. 12-13).

5. A potential empirical view

Despite the best projections of the future development, the possibilities for interaction between the projected elements remain relatively hard to predict. As Bernstein et al. (2000, p. 56) argues, the core element of the search for critical uncertainties stems from the countless possible ways in which the contemporary observed phenomenon interacts, recombines, or avoids any contact. The ultimate goal of the analysis of critical uncertainties is the uncovering of the potential threats and challenges, which should under certain circumstances appear during the progress of the timeline of the constructed scenario. Although it is difficult to project the results of the aforementioned potential interactions, the analysis concentrates on a set of three main realms of uncertainty. The set includes the formation of adversarial actors, turbulence, and transformation of climatic conditions and the adaptability of the technology on both the industry and the context of predetermined elements. While the potential for emergence of alternative results remains existent, the chosen set of phenomena remains in light of contemporary data most probable.

5.1 Adaptation to adversariality

The current rising trend of the use of computer vision across multiple realms of use highlights machine learning in both importance and security relevance. While trained models tend to be very effective in classifying benign inputs, the manifestation of adversarial inputs quite reliably possesses the ability to drastically alter the results (Madry et al. 2017, p. 1-2). The issue stemming from the emergence of adversarial data represents an extremely striking challenge, as in terms of active adversarial actions only a small alternation of input data imperceptible by humans can result in unreliability of neural networks with high confidence. More importantly the possibilities for active adversarial actions exist through both learning and classification (Huang et al. 2011, p. 43), thus the potential for successful disruption of the process arises with time. Besides the obvious security threat to the correct implementation of the technology, the vulnerability of the algorithms demonstrates the lack of underlying concepts in the deep learning process (Madry et al. 2017, p. 1).

Although the reality of active human adversaries remains fairly limited in case of the agricultural sector implementation, the natural realm poses a toolkit similarly powerful in terms of adversarial counteraction. While the contemporary situation in terms of visual distinction of weeds remains relatively stable, a great number of models struggle with high confidence classification in comparison with the crops (Liakos et al. 2018, p. 13). Despite the current struggle, the future threat to the successful use of the technology ultimately stems from a trend clearly similar to the use of herbicides and herbicide resistant crops. Initially, the use of total herbicides and more importantly the implementation of herbicide resistant crops resulted in immense production growth thanks to the practical elimination of negative influence of weeds. The natural response followed the trend of adaptation for "power vacuum" in nutrient abundant space. With the emergence of herbicide resistant weeds, which counteracted the human action, thus resulting in the proliferation of the resistant weeds, which wielded a strong evolutionary advantage (Owen and Zelaya 2005, p. 302-303).

The connection between herbicide resistant weeds and computer vision algorithms responsible for weed detection might seem irrelevant to the topic of adversarial actors, yet in reality the situations can be practically identical. As in case of use of total herbicides, the successful implementation of weed detecting and controlling computer vision-based systems should result in practical elimination of contemporary weeds from the field ecosystem. The resulting situation creates a space for new expansion in terms of natural laws, which favour adaptation. In terms of visual data driven systems, the logical adaptive mechanism is a visual mimic of crops, mirroring the resistance adaptation to total herbicides (Owen and Zelaya 2005, p. 303-306). The speed at which the weeds adapted to the use of herbicides resulted in a practical race between the herbicide producers and natural evolution of resistances, as successful mitigation of weeds remains among the most important aspects of crop yield. Visual data on the other hand practically lack the progressive mechanisms of chemical alteration of target areas (transportation protein, photosynthesis, etc.), thus the full reliance on computer vision poses a risk of unreliable weed control mechanisms.

As the empirical evidence suggests, the issues of successful implementation of machine learning technology struggle from broader systematic shortcomings. In terms of adversariality, the current structure of the algorithms faces two major challenges. Firstly, the issue of distribution shifts compromises the necessary uniformities between the training and target datasets (Špelda and Střítecký 2021, p. 4). With the current relative reliance on independence and identical distribution or invariance of "ground truths" to permutations, the models fail in dynamic environments, which disrupt the necessary stability or the data and its underlying ground-truths. Secondly, the issue of adversarial actors similarly plagues the implementation, as adversaries tend to radically jeopardize the stability of "ground truths" of the analysed data. Overall, the distribution or covariate shifts leading to disjoints of data in place of perceived uniformity can in an unbenign environment exist in both forms mentioned above (Špelda and Střítecký 2021, p. 9-10). Conclusively, the inability of current machine learning technologies to overcome the effects of unbenign environments leads to reliance on computer-human nexus assuring the correct adjustments of the system.

5.2 Climatic uncertainty

While the majority of Africa is proposed to be relatively harshly disrupted by climate change in terms of food production, the global perspective points in quite an alternative perspective. The obvious inescapable threat of up to 30 % reduction to the current limited yields by 2050 (Ringer et al. 2010, p. 10-11), remains relevant for both regional and global food security. The issue of uncertainty of potential outcome of the contemporary situation stems from two major factors. Firstly, the areas most remarkably susceptible to climate change pale in overall food production capabilities in comparison to actors such as European Union, which produces up to 20 % of both meat and cereals globally (Bindi and Olesen 2011, p. 151). And secondly, the existence of new production frontiers which in case of continuous growth of temperature expect higher yields, access to more warmth dependent crops, newly available arable land, and overall growth of own agricultural production (Aydinalp and Cresser 2008, p. 675-676).

Globalisation of agricultural production not only assures the year-round availability of fresh products, but also more importantly enables the transfer of production in accordance with the environmental factors. With the rising vulnerability of regions such as Sub-Saharan Africa or Southern Asia, the globalisation of trade assures the food security of the regions unable to feed their growing population (Ringer et al. 2010, p. 11). Thanks to the production stability of regional exporters including the European Union or United States, the initial influence of climate change might not only be compensated by the imported products. Currently the institutions responsible for planning the Common Agricultural Policy already project the possible adaptation strategies, as many of the projections of global warming effects modify the European production in both positive and negative light (Bindi and Olesen 2011, p. 152-156). Similarly, the Russian and Canadian public authorities project the future development of the production capabilities with adaptation strategies in mind.

The existence of adaptation strategies through the northern hemisphere reflects the positive effects of global warming on certain “winner” regions (Aydinalp and Cresser 2008, p. 676). Currently the northern European regions lack the capacity to intensify the agricultural production because of low annual temperatures. Yet in case of continuous warming, not only is the intensification realistic, but more importantly a new set of land ready for fertilization emerges in the northernmost areas (Bindi and Olesen 2011, p. 154). In case of most northern hemisphere regions, the trends highlight the rise of new production capabilities outside of the current bounds of crop climatic needs (Sharmina, Anderson and Bows-Larkin 2013, p. 386-387). The final aspect of the inclusion of currently unused land for food production stems from the element of counteraction of the depletion of fertile soil, as with newly developed production locations the current trend might be reversed. Although the inclusion of new territories does not assure full compensation for both the depleted and climatically unusable land, the potential for transformation of the trend exists within the projected boundaries of the models.

5.3 A natural response

Historically, two main factors have influenced the population growth across the globe. The security of basic needs, mainly food and water, and the progress of technology. The technology not only helped to mitigate any insecurities of the two existential elements, but more importantly altered the counteractive element of death through massive decrease in infant mortality and through life prolonging medical techniques (Blacker 1947, p. 88). In terms of demographics the population growth is described as a cycle with fire core phases, high stationary, early expanding, late expanding, low stationary, and diminishing. Although history includes a plethora of examples of non-existent populations, which peaked and diminished leaving behind only archaeological remnants of their existence, the understanding of the final stages of the cycle remains relatively limited. Core factors influencing population growth remain the main components for projection of the current phase of the cycle, which propose the most likely peak close to the year 2100 (Lutz Sanderson and Schebrov 2001, p. 548).

While most predictions for the twenty-first century remain in light of the rising effects of climate change, and the potential subsequent disruption of global food security, the current trends in population growth clearly do not reflect the fears of the projected future (Schmidhuber and Tubiello 2007, p. 19703). The possible outcome of the interaction between the contemporary population trend and the projected rise of food insecurity should in logical continuity point towards a radical shift of cycle phases outside of the observed trends. The core of potential transformation of the current phase stems from the potentially rising factors, such as child starvation, populace malnutrition and various migration trends, which under the projected circumstances point towards a steep reduction of fertility in underdeveloped regions (Lutz Sanderson and Schebrov 2001, p. 543-544). Finally, the projection of the loss of fertility builds upon the current influence of HIV on African population dynamics, which remains relatively unstable and thus hard to predict.

To conclude, the potential for adaptation of the population growth cycle to the environment produced by the climate change remains currently relatively limited. Most food insecurity cases remain mitigated by the availability of imported food from both climatically and economically able regions (Ringer et al. 2010, p. 11). Emergence of potential disruption of the flow of products on basis of global warming is projected by majority of estimates, yet currently the reaction of regional fertility lacks connection to import reliance. The core of the missing influence remains unclear, yet a reaction of the population to critical circumstances can in certain terms produce the necessary response. Potentially, the adaptation of the cycle can arise in turbulent terms of mass famine, prevention of which remains the main motivation for implementation of smart solutions for food production in adaptation to global warming.

6. A set of variables

Whereas the empirical dimension of the analysed issue including stable phenomenon, driving forces or theoretical underpinnings serves as the basis for construction of scenarios, the varying elements of plotlines, scenario implications and wild cards form the structural boundaries of the projected future. More importantly, the three final parts of the methodology not only allow for the complex design of the scenarios, but also help the analysis to avoid simple projection of current trends without altering influence of the "open system" of the reality (Bernstein et al. 2000, p. 56). The chapter points out the core aspects of the aforementioned elements of the methodology, while highlighting the terms under which the elements affect each of the scenarios.

6.1 The plot

The backbone of the construction of scenarios is the plot line, which represents the basic structure of the timeline built on a set of variables with certain values, interactions, and outcomes (Bernstein et al. 2000, p. 56). The lack of restricting boundaries for the formation of plot lines highlights the capability of the framework for the limitless exploration of the potential future. While most scenarios represent relatively narrow variation of the future, inclusion of radically different alternatives helps the goal of learning from the projections. Considering the aforementioned potential, the thesis contains a set of three main scenarios, which serve as the representation of both the probable narrow future projections and the wild card driven alternative. The restricted amount of included plot lines stems from the research limits of the thesis and the need for full uncovering of the inner dynamics of the scenarios, which would in a broader set of scenarios produce only limited insights.

Plotline set consists of the “Scenario A”, constructed with the goal of representation of relatively plausible, yet highly optimistic projections. Through relative stability of predetermined elements, it forms a world, where not only do the driving forces transform the technologic indications into reality, but more importantly the critical uncertainties do not hinder the progress. Although the global threats presented in the stable phenomenon do harm humanity, the negative impacts tend to be relatively minor and potentially fully mitigated. Finally, the lack of wild cards and the success of driving forces only results in implication of continuous growth in form of both adaptation and mitigation of the irreversible processes.

Alternatively, the “Scenario B” serves as the portrayal of the probable, yet much less optimistic future. Albeit both the stable elements and driving forces follow essentially the same development as in the first scenario, the successful implementation of technologies does not achieve its main goals. Not only the element of critical uncertainty points out the systematic shortcomings of the machine learning technology, but more importantly results in the lack of mitigation to the current trends. Implications of the initial development of the scenario result in continuous attempts, yet for the most part lead to the food supply crisis and disruption of population growth.

Finally, the “Scenario C” enriches the plotline set with alteration of the second scenario, with the inclusion of wild cards and relatively worse values in predetermined elements. The lack of success proposed by the second scenario, worsened by the inclusion of negative wildcards results in the total alternation of implications. The consequences both transform the early indicator of technology into a predetermined element and with the inclusion of additional wildcards start an explosion of technology. To conclude, the third scenario on one hand points to a widespread food insecurity, but on the other hand resolves the crisis by “hard take-off” leading to swift manifestation of singularity.

6.2 Implied future

In terms of the gratification of the plotlines the implication of the future passed is a remarkable factor influencing the latter stages of the developing scenario. As Bernstein et al. (2000, p. 57) states, the decision making through the fruition of scenarios remains the foundation of the plotline completion. Unlike in the majority of theories the bottom line of most decision-making stems from information-based reactions. With the food security influence on the whole society the resulting outcome of the scenarios is most likely to follow the pattern of continuation of success and disruption of failure. In simple terms, the public authorities, private organisations, or the public opinion not only follow the simple projections of reality but interact and generally influence the continuation and course of most phenomena. Even though the three scenarios included in the analysis do all contain the realm of implication of scenarios, the "Scenario C" remains the most influenced by the element of decision making.

As for the "Scenario A", the implications of the development point in the direction of continual implementation of machine learning across the agricultural industry. While the technology is allowed and motivated to continue, the result of mitigation and adaptation to the predetermined trends is the continual growth of population respectively to the sustainability of food production. Second scenario on the other hand faces implications of unsuccessful green revolution and the overall systematic imperfections of machine learning technology. In the realm of public authorities, the existing technological progress remains seen as useful, thus consequently continues. Whereas governments and private companies remain faithful to the progress, most of the population reshape the decision-making process considering global food insecurity. The conclusion of such a situation consists of sharp divides of populations, fall of regional stability in certain parts of the world, rise of self-preservatory policies and major disturbance of certain trends. To conclude, the "Scenario C" builds on comparably similar development as the second scenario, with the inclusion of wild cards worsening the overall situation of food security. The failures and rising crisis influence the decision-making implications on global scale, forcing both public and private authorities into broad cooperation with the goal of search for the final solution. Immense inflow of resources on basis of the aforementioned agreement of cooperation and the resulting technologic growth leading to the wild card driven outcome.

6.3 The randomness

The concept of randomness is in most terms an unobservable property of a generating process, which can be practically inferred only indirectly (Bar-Hillel and Wagenaar 1991, p. 429). Whereas the statistical definition of randomness opposes the possibility of the phenomenon observation, the human perception of "random" events exists outside of the original definition as it is mainly based on disruption of patterns. Now while statistical randomness and the human perception of it might in definition be truly different, the manifestation of the phenomenon in reality tend to be rather similar (Bar-Hillel and Wagenaar 1991, p. 448-449). Considering the observable existence of perceived randomness, the element of wild cards exists within the boundaries of humanly random, yet statistically only relatively improbable events and developments. Because of this assumption, the prediction of such elements poses a certain challenge to the analysis, which through a set of statistically improbable and subjectively relatively random events manifests the possibility of such future elements.

Since random wild card events possess a limited probability of occurrence, the majority of projected scenarios lack any such elements (Bernstein et al. 2000, p. 58). In terms of the thesis, the use of such scenarios proposed diversity to the limited selection of final cases, altering the range of projected variation of future events. The "Scenario C" serves the purpose of diversification of plotlines based on broad inclusion of wild card type events though its construction. The first wild card of the scenario emerges in the form of volcanic eruption in the United States, responsible for major disruption of food production in the country. Subsequently, in probability terms a second wild card represents the global cooperation formed because of newly emergent food insecurity of import reliant regions. Conclusively, the final wild card of the scenario emerges from the cooperation in form of "hard take-off" resulting in the singularity (Vinge 2008, p. 76).

7. The history of the future

Great portion of the scenario building methodology in terms of Bernstein et al. (2000, p. 70) consists of data gathering, analysis and evaluation with the goal of creation of a stable basis for the scenario building. Albeit the initial preparation phases remain irreplaceable in the process, the final step of the construction of the potential future completes the analysis through presentation of the final timelines, or alternatively histories of the potential futures. The presentation of the constructed scenarios within this chapter is divided into three parts representing the three selected scenarios representing the various potential outcomes of the contemporary situation. The chapter starts with the "Scenario A" as the element of probable optimistic set of potential futures. Subsequently continues by "Scenario B", which to a certain extent portrays the probable, yet relatively less optimistic projection. The "Scenario C" closes the chapter as the constructed manifestation of unpredictability and potential randomness of the future.

7.1 Scenario A

Although the probability of the optimistic assumptions remains to be judged by time, analysis of the potentials of the relatively ideal set of circumstances poses an insightful perspective. The "Scenario A" serves the purpose of both exploration of the less threatening version of the future as well as projection of potential solutions for underlying issues plaguing the development of solutions. In terms of the driving forces and predetermined elements, the scenarios start in exact positions, yet the "Scenario A" generally faces lack of wild card events and exists within the realm of more stable trends.

7.1.1 The future of trends

As most projections propose, global warming continues through the whole scenario by up to 2 degrees Celsius annually (Wallington et al. 2009, p. 2-3), despite the ongoing projects targeted at mitigation of the issue. While the projections of sea levels rising remain an important aspect of the socioeconomic sphere, the influence of the effects on agricultural production remains limited, as the majority of the production capabilities exist outside of the endangered areas. Unlike the effects of the sea levels the extreme weather events caused by the warmed climate, emerge as a major threat to the stability of the food production on the global stage (Ringer et al. 2010, p. 10-11). The continuation of the climatic trends additionally affects a clear continuation of the depletion of non-renewable resources in terms of fertile soil (Trnka et al. 2016, p. 239, 247) in certain regions including Sub-Saharan Africa and South Asia.

Even though the continuation of climatic trends affects depletion of resources only in limited realms, the phenomenon itself continues on basis of the global inability of adaptation of agricultural industry (Bardi EL Asmar and Lavacchi 2013, p. 228-230). Rising trends in the use of renewable energy sources in core elements of the production such as fertilizer production allow through the progressing depletion of oil reserves a slow transformation. While the reliance on fossil fuels slowly expires through the length of the scenario, the larger issue of limited number of mineral deposits remains an unresolved issue for the long-term future. Finally, the trend of population growth continues to follow most predictions pointing towards the possible peak of population close to the beginning of the next century (Lutz and KC 2010, p. 2784-2785). With the growing populations and disrupted supply productions, the importance of successful rise of the agricultural production outputs remains a core element of global politics.

7.1.2 The technology?

The stable continuation of most projected trends only highlights the negative implication of the early indicators of food shortages based on disruption of agricultural production, with increased scale in terms of the growing population. The initial stages of the scenario contain global proliferation of autonomous greenhouse production and the successful transition of vegetable and fruit production to indoor controlled environments (Mohanty and Patil 2013, p. 17). With the rising odds at play and the general reliance of populations on cereals (Pretty 2008, p. 447-448), the necessity of production growth forces the early implementation of limited machine learning tools for conventional farming. While the initial stages of implementation in both indoors and outdoors realms produce only limited results, the relative stability of the global situation allows for a period of optimization resolving the initial shortcomings. The optimization period additionally highlights the remedies for majority of the systematic flaws plaguing the machine learning technologies.

In terms of the potential complications of the emergent trends, the initial push for general implementation of machine learning in agriculture gained time and stability through the adaptation and expansion of food production. In terms of the stable trends, responsible actors such as the European Union continued in the implementation of adaptation and mitigation initiatives. The result of allocation of intensive production to the northern less stressed locations and replacement of former intensive production by extensive one in the affected regions, combined with the exploitation of formerly unusable farmland, led to relative mitigation of the production decrease (Bindi and Olesen 2011, p. 152-156). With the limitation of dangerous trends, the optimization period resulted in successful implementation of the technologies, as well as formation of a new agricultural profession based on the necessity of human "super observer" mitigating the slowly emerging effects of unbenign environments (Špelda and Střítecký 2021, p. 18-19).

7.1.3 The implications and outcome

The success of the mitigation and adaptation of the agricultural industry to the newly formed environment and the rising needs of the growing population implies continuous growth and shift of focus on non-threatening phenomena such as space exploration. In terms of the decision makers position, the logical support of additional research and further mitigation of negative climatic impacts remains a relevant topic. Albeit the food insecurity moderation averted the disruption of population growth, the extreme weather conditions throughout the world resulted in the rise of migration and further globalization. Generally, the policy makers shift of focus from food security to the subsequent results of climate change highlights the potential blindness towards the unresolved issues within the realm of depletion of non-renewable resources.

To conclude, the optimistic perspective on successful mitigation of food insecurity through implementation of machine learning resulted in a globalized world heading for a new horizons. While the process did heavily rely on outside elements of the scenario allowing for the optimization of the technological solution, the outcome of the situation highlights the potential of machine learning as a solution to contemporary threats. Despite the stability of the trends and lack of unpredictable factors certainly helped the fruition of the coveted outcome, the probability of the scenario remains within the boundaries of probable future.

7.2 Scenario B

The core assumption behind the choice of the “non-optimist” scenario stems from the broad spectrum of criticism pointed at the current attitude towards the implementation of progressive solutions. Through the use of probable trends in both stable and indicated data, and the exclusion of major wild card events, the “Scenario B” serves as a platform for examination of the shortcomings of the proposed solutions. While the future uncovered within the scenario remains in no way world-ending, the set of phenomena dictating the results of the scenario pose a real threat to humanity as we know it.

7.2.1 The future of trends

The development of the climate change within the scenario continues within the projected boundaries of annual growth ranging from 1 to 2 degree Celsius. Resulting change of climate leads to the increased occurrence of extreme weather conditions such as heat waves, droughts, or floods (O'Neil and Oppenheimer 2002, p. 1971). Likewise, to the first scenario, the development of countermeasures of the process achieves only limited success, thus the climate evolves within boundaries of projections by Wallington et al. (2009, p. 2-3). The disruption of global food supply as outcome of the aforementioned rise in extreme weather conditions emerges within the initial decades of the projected future. Although the disturbance stems from both depletion of fertile soil by erosion and the series of weather-related external stresses on crops, the extreme weather elimination of stable rain patterns represents the majority of damage done. In light of the early indications uncovered at the start of the millennia, the Sub-Saharan Africa, Australia, and South Asia face the most substantial alterations of seasonal weather.

In the realm of the non-renewable resources, the initial stages of the scenario present the slow transformation period in which personal transportation and transfer of goods eventually lose the reliance on fossil fuels. While the agricultural industry and fields such as mining remain reliant on consumption of non-renewable energy sources for prolonged periods of time, the conversion of the fertilizer production on renewable energy heralds the eventual transfer (Bardi EL Asmar and Lavacchi 2013, p. 228-230). Despite the consequent mitigation of the depletion of fossil energy sources, the issue of both limited mineral fertilizers deposits and soil nutrient deficiency remain relevant. The development of population trends initially follows the projections predicting the rise up to the start of the next century, yet after the initial phase of the scenario, the food insecurity alters the process. With the world population reaching 8 billion prior to the year 2030 (see Graph 2), the critical phase of necessary production growth starts for the agricultural industry.

7.2.2 The technology?

The climate driven food shortages first indicated by the situation in Sub-Saharan Africa in the 1990’s only continue to grow in global importance with the escalation of the population, climatic and non-renewable resources trends. Albeit the development of autonomous greenhouse farming successfully results in broad use of the technology across the developed regions in the early phases of the scenario, the majority of the food production remains outdoors. Not only the greenhouse farming remains limited to the fruit and vegetable production, but more importantly spreads slowly thanks to the financial demands of the technology. On the basis of the rising demands of the growing population, conventional outdoors agriculture enacts the implementation of various limited machine learning tools during the critical period. The early limited success of the technology allows for further limitation of necessary workforce and increase in precision. With the continuous development, the technology proliferates and results in further increase in outputs, yet the core goal of 70-110 % rise in production (Pretty 2008, p. 447-448) remains far beyond the capabilities of the technology.

While the emerging depletion of fertile and climatically unusable farmland trend continues in the majority of the globe, developed regions in the global north exploit the relatively positive potential of newly usable land (Bindi and Olesen 2011, p. 152-156). The issue of the allocation of the intensive production to the locations formerly lacking the necessary conditions stems from the unequal ratio of the usable farmland between the emerging and declining regions. The resulting situation only highlights the need for increase in production and thus forces the industry to implement machine learning tools. Although the implementation of technology increases the outputs in limited terms, the continuous use highlights the shortcomings of machine learning in terms of unbenign environments. The controlled environment of greenhouses solidifies the usefulness of the technology, yet in large scale outside implementation, the combination of distribution shifts and emerging adversarial actors hamper the success of the production (Špelda and Střítecký 2021, p. 9-10).

7.2.3 The implications and outcome

The failure of the technological solutions for the growing issue of underperformance of the food production in terms of the growing population demands results in widespread insecurity and shortage. Not only does the everlasting transformation of agrocenosis mitigate the growth of machine learning driven yields, but more importantly the prolonged use of the visual data reliant technology heralds a substantial rise in the weed populations disrupting the crop yields even further. The implied perspective of both the authorities and the public, emboldened by the critical conditions of global food security, point out the failure of technological progress, which promised a solution for climate change and food insecurity. As the population demands grow in terms of the regional food insecurity, the import reliant global south falls into chaos. The latter stage of the scenario presents a world in strife, famines leading to internal conflicts and large-scale migration resulting in a plethora of human suffering, all while the authorities search for the ideal scapegoat. As the negative attitude towards the promoters of machine learning and artificial intelligence in general grows, the logical implications of cancelled funding result in a second AI winter.

To conclude, the scenario highlights the underlying weak links of the potential process of machine learning driven empowerment of the food production. Albeit the later stages of the scenario project a relatively grim future for certain regions of the world, the selection of the global north allows for a bit less pessimistic outcome. Not only certain regions benefit from the newly available farmland, but more importantly do achieve a successful implementation of machine learning in agriculture and its positive implications. The resulting situation disrupts the progress of artificial intelligence development thanks to the results of inability of the rushed technologies to sustain the rising demands of the less developed world leading to the critical situation present at the final stage of the scenario.

7.3 Scenario C

With the practical unpredictability of the future of the world, the importance of uncovering the improbable or extreme possibilities remains relevant for successful lesson learning. Through the scenario, the combination of wild cards and their implications lead the construction outside of the probable future projections whilst highlighting alternative, less explored threats, and opportunities. The "Scenario C" consists of extreme elements and their implications which both point out both the shortcomings of the proposed technologies as well as threats outside of the contemporary empirical considerations. Unlike the "Scenario B", the extreme environment contains potentially world ending dynamics, combined with a potential for utopia.

7.3.1 The future of trends

Although the early development of the climate follows in lines of most projections, thus resulting in further depletion of fertile soil and disruption of agricultural production in selected regions, the in year 2028 volcanic event in northern California alters the trends radically. On one hand it disrupts the production capabilities of the main global food exporter (Brown 2011, p. 23-25) and home to more than 300 million people. Whereas on the other hand the immense increase in the volcanic ashes in the top layers of the atmosphere results in relatively radical and swift cooling of the global climate. Not only the food insecurity of the US citizens leads to a major translocation of global food imports on basis of economic prioritization, but more importantly the lack of their exports in combination with immense increase in imports disrupt the stability of import reliant nations. The climatic effects of the volcanic eruption include the heightened presence of reflective particles in the higher parts of the atmosphere and its result of rapid decrease in global temperatures. Resulting situation affects agriculture in two dimensions, as lowered amount of sunlight piercing the ash in the atmosphere disrupts the photosynthesis of crops (Cook et al. 1981, p. 19-21), and the decline of annual temperatures compromises the vegetation periods.

While the projections point out approximately 40 years of depletion of global oil reserves (Shaffie and Topal 2009, p. 187-188), the scenario radically changes the situation with the global influence of the 2028 volcanic eruption. In terms of fossil fuel energy, the global cooling heightens the amount of energy needed for heating as well as for logistics of food imports to the affected northern America. Additionally, with the immense amount of volcanic ash in the atmosphere, the photovoltaic industry faces unprecedented mitigation of energy outputs (Kaldellis and Fragos 2011, p. 315-317). The result of the combination of the above results in strengthened position of nuclear energy as well as shortening of the period of depletion of oil reserves. The aftermath of the photovoltaic crisis and the depletion of oil only accelerate the transition of most industries to natural gas or electricity. Besides the energy results of the explosion, the resulting contamination of large parts of the farmland in the US and Canada further progress the depletion of fertile soil. While the global depletion stagnates in light of the temperature decrease, the overall fertile soil reduction surpasses the projections.

7.3.2 The technology?

The initial stage of the scenario presents a relative growth of importance of the early indicated phenomenon of climate driven food shortages in underdeveloped regions as well as the proliferation of machine learning technology in agriculture. Similarly, to other scenarios, the indoors implementation succeeds and serves as a platform for better development of the outdoors technologies (Mohanty and Patil 2013, p. 17). Under the effects of the “volcanic winter”, the proliferation of production in the greenhouse environments and the automation of the process explodes in combination with the artificial heating of the facilities through fossil fuels. Although the successful process of automated greenhouse farming produces unprecedented amounts of food, the global needs remain far from satisfied. With the lack of major implementation in unbenign environments, the systematic drawbacks of the machine learning technology remain only a limited issue unlike the rest of the scenarios.

7.3.3 The implications and outcome

The major disturbance of the global food production systems, as well as the limited success of greenhouse alternatives result in a critical period of global food insecurity. The hungering masses combined with the starting internal conflicts motivated by the growing grievances motivate the majority of the global decision makers on a relatively risky cooperation. With the world at a brink of collapse the global community in a relatively wild card event agrees on united cooperation and funding of an attempt at creation of an artificial intelligence system capable of increasing the food production outputs. While the process itself leads to unpredicted success, the final wild card emerges in form of "hard take-off" of the artificial intelligence resulting in a singularity state (Vinge 2008, p. 76-77). The end of the scenario remains practically impossible to picture as the singularity exists so far above the human perception of reality, thus the final stage of the scenario consists of only a hope for correct alignment of the artificial intelligence.

To conclude the scenario, the implication of the savage combination of wild cards within the scenario points towards unimaginable results. Albeit the conception of singularity surpasses the probable boundaries of the majority of scenarios, the limited potential of the scenario fruition highlights the importance of disciplines regarding the dangers of uncontained technological progress. In terms of the results the prediction of the outcome of the final stage of the scenario creates an environment in which the fate of humanity manifests as a surpassed concept of existence.

8. Conclusion

The conclusive evidence presented by the three scenarios highlights the reality of the potential of the implementation of machine learning to agricultural industry. Even though all projections suggest a surge in global food insecurity as the aftermath of the climate change, the situation remains potentially soluble under the right circumstances. The main difference between the potential implications stems from a set of two goals, firstly the fulfilment of the necessary growth of the agricultural outputs. And secondly, the adaptation of the technology to the unbenign environments necessary for long-term stability of the projected food production system. While the "Scenario A" represents the successful completion of both goals, the remaining scenarios highlight the limitations and the vulnerability of the technology.

In terms of the research questions:

RQ1: How can successful implementation of data driven machine learning technology achieve the output growth necessary for agricultural industry to achieve food security globally?

Generally, the analysis concludes that the technology possesses the potential for the increase in the outputs of the industry. While the development of the greenhouse automation poses a certain field of increased productivity, the outdoors farming remains a greater issue. With the successful incorporation of computer vision weed and pest mitigation as well as machine learning big data driven platforms into the conventional agriculture, the potential growth of outputs surpasses the rising needs of the population.

RQ2: Can successful implementation of machine learning algorithms fully eradicate current obstacles to food security in agriculture?

Albeit the relativity of the question points in two potential outcomes, the successful implementation of contemporary machine learning would under certain circumstances eradicate the contemporary issues. But as the agrocenosis remains open system, the mitigation of one set of problems automatically creates vacuum attracting the emergence of new, adaptive elements causing potentially bigger damage in comparison with the former.

Finally, it remains important to state, that while the three presented scenarios allowed for relatively broad perspective on the analysed issue, the lack of the countless alternative scenarios remain core limitation of the thesis. Additionally, not all of the alternative scenarios pose a prominent change to the overall probable outcome, thus the limitation of a limited number of cases remains relative in the unpredictability of the future. To conclude, the main goal of the thesis, the exploration of the potential implications of the machine learning driven mitigation of food insecurity persists. Only a limited part of the potential was uncovered by the analysis, but the need for exploration of the full phenomena and the subsequent lesson-learning endures.

Summary

The purpose of this diploma thesis is to demonstrate the importance of the exploration of the potential future development of machine learning driven agriculture and its implications for global food security. With the detailed examination of both theoretical and empirical elements of the projected future the thesis concludes with a set of three scenarios representing both the probable and "black swan" futures. Although the extent of the explored future remains limited thanks to the selection of three final scenarios, the core systematic flaws and strengths of the field of artificial intelligence as the source of machine learning are highlighted through the scenarios.

The first scenario highlights the potential of machine learning driven agriculture to compensate for the production disruptions created by the effects of both climate change and depletion of natural resources. While the scenario heavily relies on the combination of continuous stable trends, the "optimization period" remains probable thanks to the broad category of critical uncertainties. The resulting outcome includes the adaptation of production capabilities to the changing environment and more importantly to the rising population. Finally, the scenario allows for the lessons learned in terms of the inclusion of human computer nexus, which both compensates for systematic shortcomings of machine learning and assures the future for the agrarian workforce.

The second scenario builds on a relatively similar structure as the optimistic scenario, yet with a contrasting perspective on both critical uncertainties and systematic flaws of machine learning. Albeit the overall development of the scenario projects broad negative consequences, the differentiation of the development of the different parts of the globe results in varying levels of successful adaptation. The core element of the implementation of machine learning on agriculture only further highlights the development disparity. On one hand the scenario presents a proliferation of the technology, yet on the other highlights the underlying weak links of the process as well as the inability of the technology to fulfil the expectations and needs.

Third and the final scenario represents the low probability element of the research, as most of the constructed future stems from black swan-like events (wild cards) and the resulting extreme values of variables. While the resulting future absents the solution for the core analysed issues, the resulting stage of space possibly surpasses the human perception of existence. To conclude, the scenario's main value focuses on the importance of the philosophy-technical disciplines uncovering the dangers of uncontained technological progress.

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