CZECH UNIVERSITY OF LIFE SCIENCES, PRAGUE

FACULTY OF ENVIRONMENTAL SCIENCES

BACHELOR THESIS

Investigating the scalability of agrivoltaics as an alternative to monoculture photovoltaics

2024

Department of Landscape and Urban Planning

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BACHELOR THESIS ASSIGNMENT

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Environmental Engineering

Thesis title

Investigating the scalability of agrivoltaics as an alternative to monoculture photovoltaics

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Objectives of thesis

The objectives for this BEE thesis is to study the monoculture of photovoltaics and the rising potential of agrivoltaics within the site locations for photovoltaic farms. Agrivoltaics is a new area of applied farming where the practice of growing crops underneath or around solar panels is practiced. Scientific studies show that some crops in fact thrive when grown in this way. The other benefit has to do with the doubling up on land use. This way, the act of energy generation and food production could help feed the world's growing population while also providing sustainable energy.

Methodology

The thesis research will be based upon interviews with individuals within the field of photovoltaic and agrivoltaic practice, ranging from experts to entrepreneurs. The interviews will be analysed and compared to find the most dominant factor affecting the scalability and application of agrivoltaic systems.

The proposed extent of the thesis

60 pages

Keywords

Agrivoltaic, photovoltaic, energy generation, alternative agriculture

Recommended information sources

Dinesh, H. and Pearce, J.M. (2016). The potential of agrivoltaic systems. Renewable and Sustainable Energy Reviews, [online] 54, pp.299–308. doi:https://doi.org/10.1016/j.rser.2015.10.024.

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Jo, H., Asekova, S., Bayat, M.A., Ali, L., Song, J.T., Ha, Y.-S., Hong, D.-H. and Lee, J.-D. (2022). Comparison of Yield and Yield Components of Several Crops Grown under Agro-Photovoltaic System in Korea. Agriculture, 12(5), p.619. doi:https://doi.org/10.3390/agriculture12050619.

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Expected date of thesis defence

2023/24 SS – FES

The Bachelor Thesis Supervisor

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Supervising department

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Electronic approval: 21. 11. 2023

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Prague on 27. 02. 2024

Declaration

I hereby declare that I have worked on and written this bachelor thesis named "Investigating the scalability of agrivoltaics as an alternative to monoculture photovoltaics" solely by myself and cited all appropriate sources that I have worked with and been exposed to along the entirety of the writing process.

I also declare that the printed version of this dissertation is identical that to the electronic version and that it does not infringe on copyrights. As the author, I hereby affirm and attest that I have used Artificial Intelligence tools in compliance with the university's regulations, and references to those tools have been made available.

Date: 19.03.2024 Signature:

Acknowledgements

I would like to convey my deep gratitude to my thesis supervisor doc. Peter Kumble, Ph.D. for his expertise and guidance throughout the process of writing this thesis. Furthermore, I would also like to thank all the interviewees for taking their time within their busy schedules to answer my questions and giving me a new perspective on the topic of agrivoltaics and each offering a unique set of ideas. I wish to express my sincere appreciation to my father, for initially introducing me to the topic of photovoltaics and giving me unforgettable opportunities. Lastly, a special thanks is due to my close family and friends for supporting me throughout the entirety of the process.

Abstract

This thesis aims to investigate the viability of a sustainable approach with agrivoltaics as an alternative to monocultural and conventional use of photovoltaic systems. It addresses the aspects that affect the possible spread of this technology throughout the world, offering a new innovative approach to sustainable development. With the current demand for renewable energy development, agrivoltaics, a technology utilising land underneath photovoltaic structures for agricultural purposes, is a strong candidate for future use. Interviewing field-experts, from researchers to project managers within the sector, is a major component of the methodology, which seeks to inquire about said viability. The results of this study point to the barriers that most affect the possible use across different regions, with financing being the biggest obstacle, as well as the farmers' interest and legislative frameworks. However, the study concludes that if agrivoltaics are kept at a small-scale level throughout the landscape, it can act as a viable alternative to both conventional photovoltaic farming as well as monocultural agriculture. This could suggest a paradigm shift in the renewable energy sector, offering a new set of opportunities as well as possible innovative research.

Keywords

Agrivoltaic, photovoltaic, energy generation, alternative agriculture

Abstrakt

Tato bakalářská práce se zabývá schůdností udržitelného přístupu agrovoltaiky jako alternativní možnost monokulturního a konvenčního použití fotovoltaik. Zaměřuje se na aspekty, které nejvíce ovlivňují světové rozšíření této technologie, umožňující nový inovativní přístup k udržitelnému rozvoji. S tím, jaká je nyní poptávka o obnovitelné zdroje elektřiny, jsou agrovoltaiky jako technologie, která používá půdu pod fotovoltaickými panely k zemědělskému užitku, velmi silným kandidátem pro budoucí použití. Rozhovory s experty ze sektoru, od vědců po projektové manažery, jsou hlavní součástí metodologie, která se pokouší získat odpověď na již zmíněnou schůdnost této technologie. Výsledky studie poukazují na největší bariéry, které nejvíce ovlivňují použitelnost v různých koutech světa. Největší dopad má financování, zájem zemědělců a legislativní možnosti. Zároveň je ale usouzeno, že budou-li agrovoltaiky zanechané jako malé projekty v krajině, můžou sloužit jako alternativa, jak pro tradiční fotovoltaické farmy, tak i pro monokulturní zemědělství. Toto by mohlo naznačovat posun paradigmatu v sektoru obnovitelné energie, což by mohlo přinášet novou sadu příležitostí a další inovativní výzkum.

Klíčová slova

Agrovoltaika, fotovoltaika, generace energie, alternativní zemědělství

Table of Contents

1 Introduction

In recent years, the global demand for renewable energy has surged due to both the high energy prices and the current climate crisis at hand. As a result, photovoltaic (PV) systems have become a sought-out commodity, both on a consumer and large-scale level. However, with the extensive land use required for photovoltaic farm installations, environmental concerns have been expressed, which, in turn drives innovation. Agrivoltaics, a technology utilising land underneath solar panels for agriculture has been developed and applied on experimental levels all around the world.

Current research studies have identified and promoted the benefits of agrivoltaic implementation on a small-scale basis, though a significant unaddressed question remains. That is of the understanding of its environmental viability and scalability in terms of possible obstacles. The thesis focuses on the implementation of agrivoltaics not only in the Czech Republic, but also on an international level.

The aim is to investigate to what extent agrivoltaics can be applied at different scales as an alternative to monocultural photovoltaic farms and its environmental implications. This assessment will be completed through a thorough study of current results on agrivoltaic system studies, personally attended conferences and case study sites, as well as individual interviews with field leading experts from different backgrounds and of different nationalities.

The study is of great significance through its contribution to research on sustainable development solutions and adaptation methods to climate change. Furthermore, it offers insights on expert-opinions, agrivoltaic viability and inform on areas of focus when implementing agrivoltaics and realising projects during policy and legislative procedures. Lastly, it aims to inspire further research not only on the topic of agrivoltaics, but also on other sustainable renewable energy solutions and their integration on a national and international level.

2 Objectives

This thesis focuses on the alternative and more sustainable solution to both a monocultural use of photovoltaics, as well as the sustainable management of agricultural areas. The aim is to determine the most prominent factors affecting the scalability of agrivoltaics, and to question the scalability aspect of this innovative technology. Interviews with field-experts and environmentalists of different backgrounds and nationalities will be conducted to provide the best possible overview within the field of agrivoltaic technologies.

LITERATURE REVIEW

3 Photovoltaics

Photovoltaics, a technology often referred to as solar panels, or PVs (photovoltaics) are a technology that has been on the rise approximately since the mid-20th century. The technology's primary objective is the conversion of solar energy directly from the Sun into electrical energy using solar cells or panels.

The cells are made from two different types of materials that act as semi-conductors: p-type (positive charge of electrons) and n-type silicon (negative charge of electrons). When the surface of the cell is in contact with photons from the sun, electrons are released, resulting in the creation of an electric charge. The p-type gets its name from the positive charge within the cell that is created, because of the presence of positive boron atoms. In a similar manner, the n-type gains a negative overall charge through the presence of phosphorus. While p-type solar panels are a more popular option within the photovoltaic market, it has been scientifically proven that n-type photovoltaics are have a longer lifetime, as presented by Cotter et al. (2006). Among other reasons, this is a result of pure convenience and historical manufacturing practices. This stems from the space industry deeming them more suitable for their utilisation due to the better end-of-lifetime performance (Cotter, et al., 2006).

There are many different types of photovoltaic systems used today, from small-scale to large-scale applications all around the world, even on a consumer level. These can be ranging from solar farms through rooftop installations, even to a solar powered flashlight.

According to the International Energy Agency (IEA, 2023), PV modules are the leading renewable technology in the private sector and predicts for solar energy produced to surpass that of coal by 2027. Furthermore, we can also observe an increase in the generation of electrical energy through the usage of PVs by 26% in 2022 compared to the results in 2021. Overall, this accounts for 4.5% of all electricity generated around the globe, as shown in figure 1.

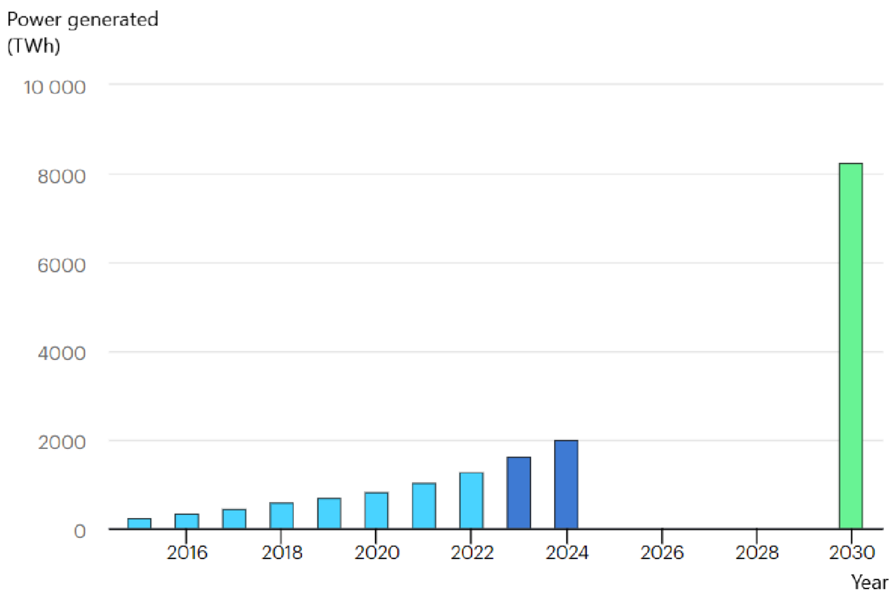

Figure 1: Solar power generated and the projection of its increase until 2030 (IEA, 2023)

3.1 History of the use of solar power

The application of solar power has been noted all throughout history. To name a few, the first noted human use of solar power dates back to the 7^{th} century B.C., through the use of sunlight for fire ignition (Energysage, 2023). In the 3^{rd} century B.C., the Greeks and Romans were known for exploiting the reflective nature of mirrors, employing them to light ceremonious items, such as religious torches. Moreover, in the 16^{th} and 17^{th} centuries A.D., scientists invented ovens powered by solar energy through sunlight on extensive sea voyages. Overall, solar energy and sunlight have been a critical part of humanity's lives, from enabling food production, food curation to energy generation.

3.1.1 First implementation in the world

The first demonstration of converting solar energy into electrical energy took place during the Industrial Revolution by the French physicist Alexandre Edmond Becquerel (Fraas and Partain, 2010). As Fraas and Partain (2010) suggest, the scientist made an observation in 1839 of a generated current when brass plates were exposed to sunlight. His revelation led to further investigations by other scientists utilising selenium, cuprous oxide or selenium with gold leaves, which generated a constant current. Consequently, the first ever operating solar cell was invented by an American physicist Charles Fritts in 1883 (Institute for Energy Research, 2023), though still harnessing very low conversion efficiencies of $<1\%$ (Fraas and Partain, 2010).

Solar cells as we know them today were perfected and introduced in 1954 by a research organisation known by the name of “Bell Laboratories”. The U.S. (United States) government continued funding the research of increasingly efficient PV panels, as a high potential source of energy was seen for space satellites. The research centre was able to further develop solar panels with a higher conversion efficiency of ~ 6%, with the use of the monocrystalline solar cell (for further details, see section 3.2.1) (Fraas and Partain, 2010). Consequently, photovoltaic panels have had the chance to become popular as we know them today.

Additionally, a majority of the solar panels in place have been installed after the 1990s, as soon as it became a more affordable consumer commodity. As the life expectancy of solar cells is expected to be around 30 years under normal operating conditions (Kim et al., 2021), a lot of modules are currently approaching the end of their lifespan, requiring repair or replacement. This can be seen as an obstacle, due to the high cost of their production and the lack of resources for their recyclability (personal communication, Wimmerová, May 2023).

3.1.2 Basic Legislation within the European Union on PV panels

As the installation of PV panels is currently a topic of interest, the European Union (EU) is pushing towards a future of sustainable development to meet sustainable development goals (SDGs). Thus, the key elements of the legislation surrounding it ought to be discussed accordingly. This applies for both the EU and the Czech Republic. The main directive that drives this forward is Directive 2009/28/EC, which establishes a framework for the future use of renewable resources (Official Journal of the European Union, 2009).

Firstly, the most important element of Directive 2009/28/EC mandates that each member country must meet specific quota targets and objectives on renewable energy produced and used by 2020. However, each member of the EU has obtained a different objective. Given that the starting point of available infrastructures of each country differs, each member has been set a different objective.

Although each country has different objectives, all the members are required to establish clear and concise “Renewable Energy Action Plans”, which outline the steps that will be needed to take to meet the goals. As a part of that, the directive also acts as an outline for the system “Guarantee of Origin”, which ensures that consumers are provided with access to transparent information on the source of their electrical energy (Official Journal of the European Union, 2009).

An important part of the directive is dedicated to access to the grid. The electricity grid is the system which allows the connection between the source and the consumers of electricity. As a part of the directive, solar energy should be shown “priority dispatch”, thus prioritizing its transmission as soon as it enters the grid over other forms of electricity generation, such as fossil fuels. This ensures the availability of it and fair treatment when faced with electricity generator “giants” (Official Journal of the European Union, 2009).

Furthermore, as an incentive to increase the amount of solar power generated, financial funding and support are needed for the consumer or person installing them on their buildings or in the landscape. Investment or feed-in tariffs are some of the means by which the growth of the solar network is being supported. What’s more, the bureaucratic process is being reworked, making the application and building of PV facilities more accessible and easier to implement based on government subsidies, as the Official Journal of the European Union (2009) states.

The above statements are just fragments from the directive, though the entirety of the legislation is dedicated to increasing the availability of renewable energy both to the producers as well as the consumers. For more detailed information, refer to the Journal directly.

3.1.3 From first installation to current trends in the Czech Republic

The very first date of installations of photovoltaics in the Czech Republic was in the later years of the 2000s. The number of installations skyrocketed in 2009 due to the novelty of the technology entering the market, which grew exponentially until 2010. The country was suddenly enriched by 2000MW (MegaWatts) of capacity for solar generated energy (EnergyTransition.org, 2019). However, as EnergyTransition.org suggests, the number of solar photovoltaics, both small-scale and large-scale farms plummeted and continued to do so until around 2018. This was a result of political disruptions and a bad outlook within the media on people who owned photovoltaics, as well as retracted governmental subsidies.

Since then, the number has been steadily rising and in 2022, Energie bez emisí (n.d.) reports a record for the most electricity generated by solar power. Many sources indicate that the current Russian-Ukranian war has had a major impact on the availability and expenditure for generating and providing electricity. The shockwave resulted in the reshaping of the entirety of the European electricity market. Due to Europe’s dependence on a Russian supply of electricity, this influx of power was suddenly cut off. Approximately 80% of the influx of gas originating in Russia was cut off between May and October of 2022, which resulted in a very prominent gap in the availability of gas. Furthermore, with the combination of EU directives and policies on power generation, this has led to less dependence on non-renewables (Thomson, 2022).

3.2 Different types and constructions of PV panels commonly used today

There are many different types of solar panels, including Monocrystalline, Polycrystalline, Thin film, Bifacial, Concentrated PV and Perovskite. These are the commonly used today and each has its advantages and disadvantages, while each type might be used in different conditions, depending on the consumer's intent and surrounding circumstances or environment.

Crystalline silicon is the main material (90%) used for the manufacturing of solar cells, of which one third is the use of monocrystalline silicon and the rest is polycrystalline silicon (Dobrzański et al., 2012). However, these materials are often very expensive, thus resulting in very high initial building costs.

3.2.1 Monocrystalline silicon solar cells

As previously stated, monocrystalline silicon solar cells account for a third of all crystalline silicon photovoltaic cells in production. It is no surprise, however, as the material has the "highest conversion efficiency of all solar panels" (Dobrzański et al., 2012). Each module consists of one single crystal, which is the uniqueness of this type of module. See figure 2 for its visual inspection.

Though this is a very intriguing asset, and possibly a decisive aspect of the installation of monocrystalline solar cells, the production costs can be very high. The investment funds needed for the manufacturing process and raw materials are the largest when compared to other types, such as polycrystalline or thin film. The main expenses of the production are concentrated within the energy-intensive process needed for the manufacturing of single crystals used within the solar cell.

Despite the benefits and disadvantages mentioned above, there are also other advantages in the usage and application of monocrystalline photovoltaics. By way of illustration, besides their longevity and due to the incredible efficiency, they bear the advantage of space efficiency, as the electricity generation target can be met through the utilisation of less solar cells when compared to the other types. Thus, technically the investment costs are worth it, as less materials will be needed when utilising monocrystalline when generating the same amount of energy with a polycrystalline or thin film. As a result, it can be argued that monocrystalline panels are landscape efficient. Furthermore, monocrystalline solar panels are more suitable for applications within warmer climates, as their aspect of being heat resistant is another characteristic that contributes to their possibility of global use (Solar Optimum, 2023).

Figure 2: Monocrystalline solar cell (dynamicslr, n.d.)

3.2.2 Polycrystalline silicon solar cells

Polycrystalline solar cells are visually very similar to monocrystalline cells, as shown in figures 2 and 5, though more cost-effective. This can be attributed to the lack of an energy demanding step of manufacturing of single crystals for monocrystalline modules. Consequently, we can see a drop in the efficiency of this type of solar panels, as illustrated in figure 3, when compared to polycrystalline, which do not require this power intensive process.

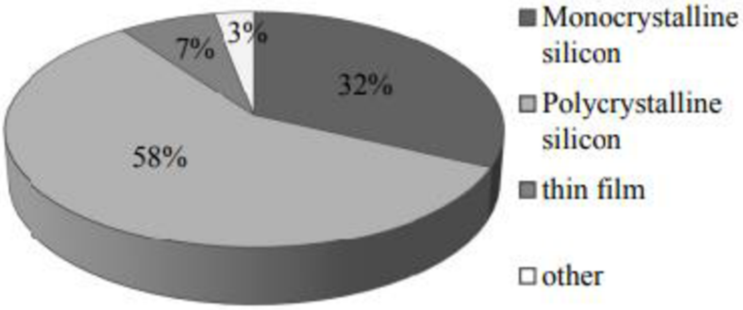

Figure 3: A summary of different solar panel types in electricity production (Dobrzański et al., 2012)

As a result of the combination of minimally decreased efficiency and cost effectiveness visible in figure 3, the popularity and desirability of polycrystalline solar panels is extremely high, as depicted in figure 4. As a result, the demand in the private sector, especially for personal use and small-scale use and application, for example on residential roofing of housing, is increased. Thus, the majority of the consumer market is made up of polycrystalline solar panels.

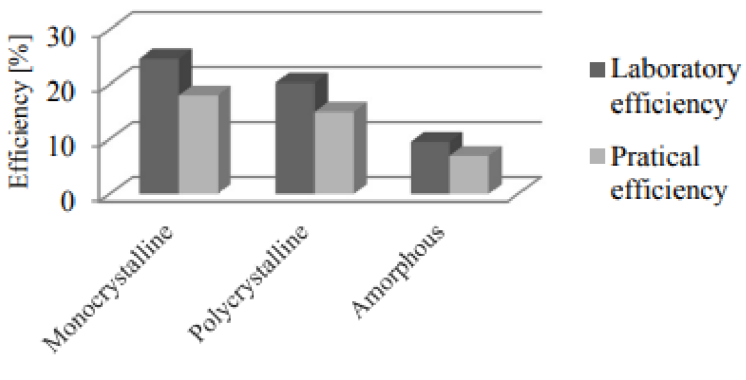

Figure 4: Efficiency of monocrystalline versus polycrystalline and amorphous solar panels in different working conditions (Dobrzański et al., 2012)

Figure 5: Polycrystalline solar cell (AdobeStock, Soonthorn, n.d.)

3.2.3 Thin film solar panels

Thin film solar panels (see figure 6 for a visual representation) consist of an extremely thin layer of amorphous silicon – a highly conductive material, which is covered in other less expensive materials, such as Cadmium Sulphide (CdS) or Cadmium Telluride (CdTe) to achieve a reduction in its initial costs (Chopra, Paulson & Dutta, 2004). The components and raw materials needed for the production of thin film solar cells usually include 96% of amorphous silicon and 4% of other materials, according to Dobrzański et al. (2012).

Other than monocrystalline and polycrystalline solar cells, the entire rest of the market is made up of thin film – and accounts for approximately 7% of generated electricity from solar farms, as indicated in figure 3.

The efficiency of thin film solar cells is significantly diminished, as can be seen in figure 4. This is a result of the lower quality of materials used in production, as well as the fact that the layer of amorphous silicon is extremely thin, resulting in a low-quality product altogether. Consequently, thin film cells are highly sensitive and dependent on good product care (Chopra, Paulson & Dutta, 2004). However, due to their availability, it might be more accessible to the general public, thus have the possibility to become more popular, though unsustainable, as the technology will likely need to be replaced more often than the other types mentioned above.

Figure 6: Thin film solar cell, (www.tesa.com, n.d.)

3.2.4 Bifacial solar panels

Bifacial solar panels are a more recently developed promising and well-constructed technology, which generates more electricity in smaller areas, as it utilises the Earth's albedo effect. The albedo effect is better known as the fraction of sunlight reflected back off the Earth's surface and is often talked about within the polar regions. This is achieved through light reflection and its further absorption by the cell both from the front (upper) and the back (lower) surface of the solar panel, thus earning its name of bifacial or "two faced", as can be observed in figure 7. Bifacial solar panels have been investigated since the 1960s and has proved to increase the efficiency of power generation through solar, up by 50% (Cuevas et al., 1982).

Bifacial solar panels are beneficial in areas where space efficiency is the priority, while tackling electricity generation expediently. This is because most of the panel's surface area serves for the generation of power. Moreover, when utilised in the combination with a tracking system, the costs can be reduced to as much as 16% (Renogy United States, 2023). What's more, the rate of generation of electricity can increase as much as 50%, as evidenced by Cuevas et al. (1982) when an albedo-inclusive solar panel is used.

Figure 7: Bifacial solar panel - generating electricity on both the front and back of the solar panel (DNV, 2022)

3.3 Why can photovoltaic farms be considered to be "monocultural"?

In high-income countries (HICs), with widespread access to heavy machinery and a substantial subsidy to plant food crops; the agricultural practices and settings are often monocultural. It is more so than in low-income countries (LICs), where traditional practices for sourcing food have been supported, promoted and kept a priority (Balogh, 2021).

The same analogy can be used for expansive photovoltaic systems, as they are usually installed in large areas, if not hectares of land, as is visually represented in figure 8. As there is no legislation that governs the management of fields under solar arrays, each owner is free to choose any method of utilising the land underneath. However, most choose keeping unprotected soil or frequent mowing for good access. In the combination with unfamiliarity of invasive or local plant populations, this contributes toward the lack of local biodiversity. Consequently, erosion and an increased risk of flooding and extreme impacts from weather conditions and phenomena are more likely to happen.

Furthermore, as the Cornell blog "What's cropping up?" (Lawrence, 2022) suggests, different types of field management methods vary greatly in the methodology of cultivating the land after construction. As a result, investors might not be keen on keeping up with the additional expenses towards caring for the land.

In conclusion, the answer to the question "Why can photovoltaic farms be considered as being monocultural?", is very subjective. However, considering the ignorance of corporations and the greed and or need for profit, it can be assumed that in most cases, the biodiversity associated with the solar farms will be overlooked and not taken into account in large and expansive solar projects.

3.3.1 Case study of a monocultural photovoltaic farm with extreme consequences

Poorly planned extensive photovoltaic farms with no landscape management applied can have extreme consequences on the surrounding landscape, ranging from a decreased biodiversity of both fauna and flora, to erosion risk and flooding of sediment. This was observed within a case study, personally communicated by Dan French (January 27, 2024), of a thousand-acre solar farm implemented in Georgia, U.S.A.

The solar farm in Georgia has skipped planning and grading of the land properly, solely applying solar panels on land. As a result, no sooner than the first larger rainstorm has appeared, huge flooding and washing out of a nearby 20-acre pond property took place. The damages have been estimated to $10-12million, though the jury within this case has awarded $135.5 million in punitive damages as a result of poor planning and low levels of land management applied. (Associated Press, 2023)

Figure 8: Huanghe Hydropower Golmud Solar Park, a monocultural photovoltaic farm (Qilai Shen, 2018)

4 Agrivoltaics

Agrivoltaics are an innovative and emerging technology, as depicted in figure 9, utilising land underneath photovoltaics for sustainable agriculture, for the dual use of land, while promoting biodiversity. It is a technology that is still being experimentally tested on, to see its viability for sustainable development. Agrivoltaics are an innovative solution for tackling modern problems, such as land shortages, for example in the Netherlands, as was personally communicated by the ambassador of the Kingdom of the Netherlands to the Czech Republic, Daan Huisinga (February 29, 2024). What's more, it is also an opportunity to incorporate sustainable solutions on a realistic level, while including major stakeholders.

The technology operates photovoltaics in the forms described above in section 3.3, though choosing the corresponding type may depend on the surrounding factors and what type of crops are chosen. However, there are many different of pursuing an agrivoltaic system, from "aquavoltaics", planting of crops to grazing of animals, though everything is ultimately governed by the country's legislation and permits.

Furthermore, depending on the type of farming technique and crops – namely orchards or vineyards and a more conservative type of agricultural practices, for example wheatfields or soya, barley, and many others, affects the type of solar setup.

Figure 9: Experimental interspace agrivoltaic system in Austria, University of Natural Resources and Life Sciences, Vienna (Pechlátová, 2023)

4.1 History of agrivoltaics

Armin Zastrow and Adolf Goetzberger are the original creators behind the first theoretical agrivoltaic system in 1981. The project's aim was to increase the effectiveness of the land as much as possible, and with the addition of the PV by Nagashima, the first agrivoltaic farm was established in Japan in 2004 Chiba Prefecture initiated by Akira Nagashima (Tajima & Iida, 2021).

It was in 2011, however, that it was published and named an "agrivoltaic" (Eduard, n.d.). Although, the innovative technology still harbours many different names across the world, for example "agrivoltaics", "agrophotovoltaics", "agrivoltaics" or even "solar sharing".

4.1.1 The agrivoltaic market and its economic outlook

As of 2021, Japan had exactly 1,992 registered agrivoltaic farms. Although that number might seem large, the agrivoltaic farms in the Asian-Pacific region are geographically not the most numerous in the world (see Figure 10), due to the technological surge in other areas in the agricultural sector.

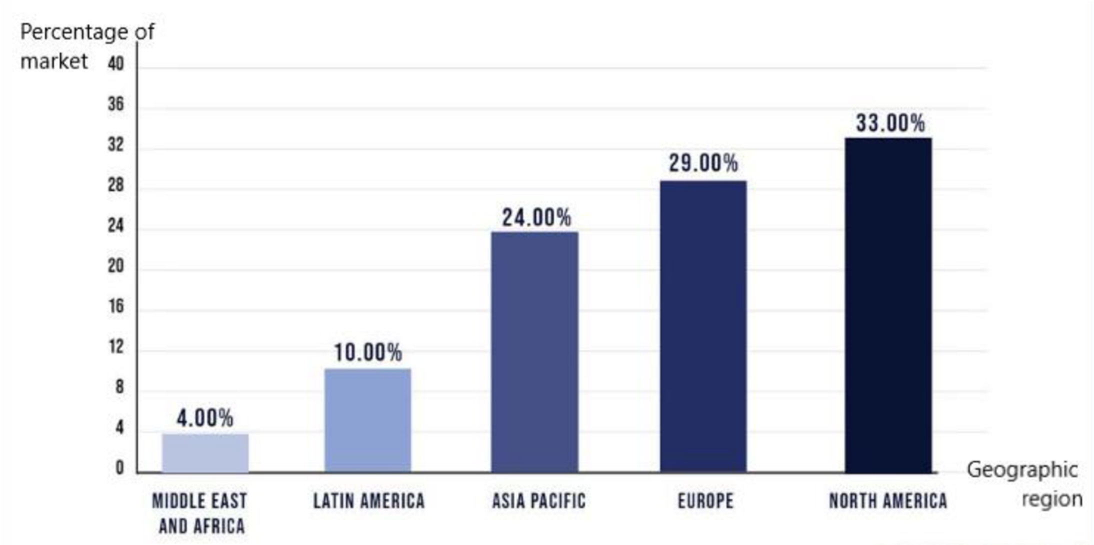

Figure 10: Share of the agrivoltaic market ($4.11 billion in 2023) by geographic region (www.precedenceresearch.com, 2023)

As seen in Figure 10, the market value of the agrivoltaic sector is valued at $4.11 billion in 2023, of which North America is the leading sector. As mentioned above, this is due to the technological advancements within this region. However, according to Precedence Research (2023), the projected market value by 2032 is to be worth $11.14 billion. According to the research, this can be attributed to many different drivers and factors, such as a rise in popularity of innovative, alternative and more sustainable farming systems. The rising population drives the supply and demand of both food security as well as electricity; both factors are the main requirements of the agrivoltaic farm, thus creating demand for these systems. Moreover, the drive towards more polyfunctional uses of land, due to the pressure from effects of climate change, is advantageous when resources are increasingly scarce.

All these drivers are a motivation for other emerging market opportunities. Precedence Research points to examples of this phenomenon that include the emergence of the innovative technology within lower- and middle-income countries (LIC, MIC). This is seen as an opportunity by the communities of India, Brazil or China, to harbour advanced technologies that are, as mentioned above, polyfunctional.

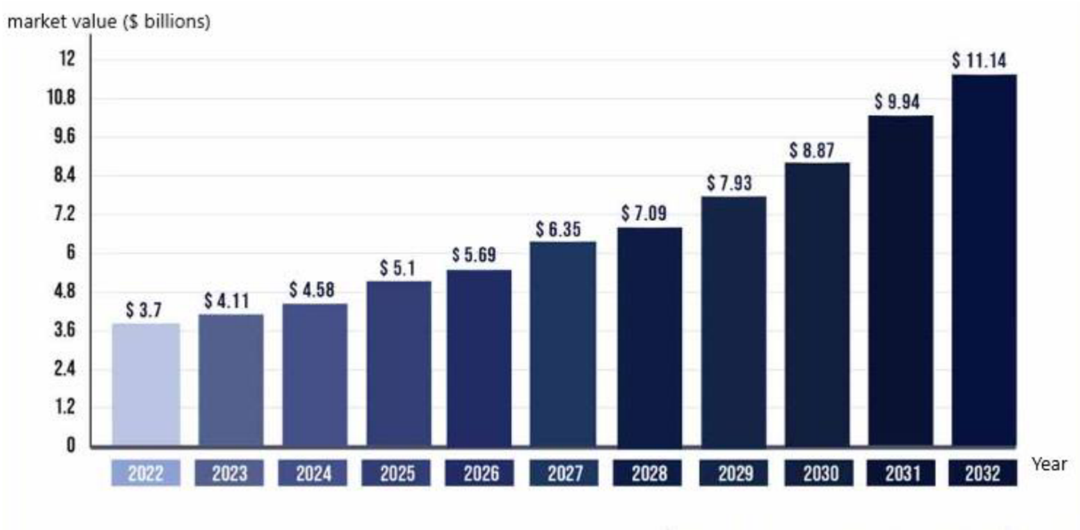

Figure 11: Agrivoltaics market size projections 2022-2032 (USD billion), (www.precedenceresearch.com, 2023)

4.1.2 Legislation for agrivoltaics around the world

The legislative laws and specific guidelines are dictated by each country on its own. Thus, there is no global legislature governing the application and rise of agrivoltaic systems, like within the United Nations or the European union. Many countries have been utilising agrivoltaics as an alternative form of farming for years, thus legislature has been available. However, since this is still an emerging and innovative technology within the solar industry as well as the farming industry; more and more laws, regulations and directives are being made, and some countries don't have legislation for the building and application of agrivoltaic systems whatsoever. An example of this can be found within the Czech Republic (as of March 2024), where legislation for this is still underway.

Although, it is important to look at some existing legislation that governs the possibilities and the applications of agrivoltaics, for example in the United States of America or Japan, where the legislative directives have been established for many years.

In the USA, there has been a directive passed in 2023 by the Congress called the "Protecting Future Farmland Act of 2023" also known as the "Bipartisan Farmland Act", which aims to amend the Farm Security and Rural Investment Act of 2002 and targets the modification of the programme called "Rural Energy for America Program" (REAP) (Protecting Future Farmland Act, 2023). The bill strictly defines an agrivoltaic system to be one deployed for the harnessing of solar power while utilising the land for a dual agricultural purpose, for either crop or livestock production on a single piece of land. Moreover, the objective of the directive is one of the provisions of a structured framework for the overall protection of land used for agrivoltaic purposes. Furthermore, the act requires for the Secretary of Agriculture to step up and conduct various studies to point out the benefits of applications of the technology, as well as provide programmes to aid in technical needs for the individuals within the farming sector who are interested in pursuing and building agrivoltaics (Protecting Future Farmland Act, 2023). In summary, the act aspires to promote the market and raise its potential, agrivoltaics, as an emerging technology are truly promising and very attractive for the USA's market, as they are also the key players within the field, as is outlined in figures 10 and 11.

Japan can be considered to be a pioneer in the application of agrivoltaic systems, spearheading the innovation and applying it at commercial levels at this point. As of 2021, Japanese authorities try to meet the demand for agrivoltaic installations, as they have reached the output of 200MW (Bellini, 2021), by creating new legislations and regulations, directing the way in which the technology will be applied and the clear boundaries of what is considered an agrivoltaic. As a response to the production and application success, their preliminary goal is the increase of the number of agrivoltaics within the country. Some others include the specification of metrics and the ruling out of some projects that were agrivoltaics up until then, such as horticultural greenhouses. Furthermore, another important aspect of the legislation is the discussion of the planning process – a solar plant is an agrivoltaic only if it has been specified and planned for in the design stage of the project.

4.1.3 Legislation in the Czech Republic

The legislation directive for agrivoltaic systems, as of March 2024, is still in the works among the Ministries of the Environment and Agriculture and still within the editing stage. However, some premature information regarding its contents have been released for the public. Fakulta elektrotechnická, ČVUT (2023) summarises its contents; agrivoltaics are to be allowed exclusively on lands with orchards, hops or vineyards. This poses great restrictions on agrivoltaics' development. Although the document will outline the list of authorised crops in a joint decree of both ministries. As opposed to the legislation in the USA as well as Japan, as described in section 4.1.2., this preliminary draft can by no means, be considered extremely limiting.

"It does not make sense for the Czech Republic to allow agrivoltaics only for growers of orchards, hops, and vineyards. The main reason is the geographical and climatic conditions that may be suitable for the installation of vertical systems in the Czech Republic. These can, under certain circumstances, produce even more energy per installed kWp than southern installations" (Bím & Neugebauer, 2023).

Moreover, the Czech Republic is a country with one of the hardest-to-obtain building permits. As a matter of fact, according to Kenety (2019), in 2019, Czechia was in 157th place in world rankings among the length of the process to gain a building permit. Thus, obtaining a permit for the construction of an agrivoltaic farm, for example in the case of an orchard or vineyard, will pose a significant challenge. Consequently, the implementation of agrivoltaics will become quite hard to do for farmers, possibly having a negative effect on the rates of interest. In addition, the average time taken to obtain a building permit in the Czech Republic is around 246 days (Kenety, 2019).

4.2 Types of agrivoltaic solar panel arrangements

There is a diverse selection of system approaches to agrivoltaic farming, each targeting a different crop type in terms of the technology and positioning of solar cells. These different methods include elevated panel systems, overhead photovoltaics, interspace photovoltaics and rotating canopies. Another type may be the grazing of animals underneath or around the panels. This could potentially be considered as controversial, as some places do not recognize this type of agrivoltaic as an agrivoltaic, but a mere photovoltaic.

4.2.1 Elevated panel systems

According to ENGIE Innovation (2022), elevated panel systems are photovoltaic panels mounted on top of rigid steel structures in a standard height of 2-6m above the ground, as illustrated in figure 12. This allows for heavy machinery to drive under them without any limitations. However, the costs of this method are very high and are larger than for a normal photovoltaic, much like the other types.

The most suitable food plant species for elevated systems are crops that command a high market price. If cash-crops, such as orchard fruits, are cultivated, the larger upfront expenses will be recuperated faster. The structures are most commonly built on a larger scale in France; the French developer TSE has been a key player within the field and is introducing more and more agrivoltaic farms to the market (Deboutte, 2022), as shown in figure 12.

Furthermore, this technology could be enhanced and is projected to be very popular in combination with thin film solar cells, as detailed in section 3.2.3. Due to its marvellous property of being lightweight, it enables the building of less rigid structures. Hence, the technology can become more cost-effective and available to the general consumer (Warley, 2023). Attributable to the small mass of the modules, flexibility of use and adaptability in different conditions are increased. The light properties of the thin solar panels also serve advantageously when handling them in terms of logistical reasons, such as transport. Thus, elevated panel systems could be used on a larger scale, as no special machinery is required, and normal farming equipment can easily drive underneath the panels and constructions.

Figure 12: Elevated agrivoltaic system, France (Tse.energy, 2022)

4.2.2 Overhead PV

Overhead photovoltaics are physically somewhat like the elevated solar system (section 4.2.1), though slightly different in some aspects. The crops are still cultivated underneath the semi-transparent solar panels, usually fruit tree orchards, vineyards, or hops. However, the solar panels act as a sort of protection medium against the elements as well as animals; the main benefit is the support in providing shade and avoiding extreme weather conditions, as well as protection against birds and other wildlife.

The main difference between these two types of agrivoltaics can be mainly observed within structures the two are on top of. While the elevated system has a rigid steel foundation from which the solar panels protrude and give the illusion of "floating" around in the air, the overhead photovoltaics are T-shaped roof-structured metal compositions (Bellini, 2022). The panels are then placed on top of the structure, for further clarification, see figure 13 and 12. The structure may still allow for machinery to pass underneath the slots, though usually ones that are smaller and more compact, though that does not necessarily have to be the case, as the size can be different in each project. The solar module is usually placed at an angle of 30°, and can have a double-facing solar panel, meaning that the modules create a roof-like structure. For this reason, higher energy harvest yield can be obtained, due to the possibility of collecting solar energy from two cardinal points.

Figure 13: Overhead solar system, Austria, Heidegg (ecowind.at, 2023)

4.2.3 Interspace photovoltaic system

Interspace agrivoltaics are the most known for their cost-effectiveness and easy realisation, while keeping up effective yields (Trommsdorff, 2021). The author further discusses the possibility of increasing yields with this system. The structures are usually placed vertically, employing a bifacial photovoltaic system, as depicted in figure 14. A space among the agrivoltaics is created, ranging from 6-15 meters in width utilised for farming among the solar modules. The panels are commonly placed in an east-west cardinal orientation, thus being the most efficient in generating the most electricity in the morning and the afternoon hours, according to Trommsdorff et al. (2022) and as personally communicated with Janna Hilker, a Next2Sun project manager (2024). Though other types of solar panel arrangements can be used, depending on the plan, site and other conditions. This has been implemented on smaller scales. However, one large scale arrangement was built in Germany, as of 2022, where forage and fodder have been cultivated and harvested.

Figure 14: Machinery operating within an interspace agrivoltaic system (Next2Sun, n.d.)

Though the main goal of these structures usually aims at electricity generation, the yield can be of great significance as well (Trommsdorff et al., 2022). This is due to the fact that the interspace structures are usually built lower than a normal overhead photovoltaic system, as detailed in section 4.2.2, and the comparison is depicted in figures 14 and 13. As a result, an interspace agrivoltaic system gains a better access by heavy machinery for the cultivation of crops, as seen in figure 14. However, further scientific research and innovation can enable the emergence of other possible technologies, advancing innovation through the demand.

The disadvantage of these interspace agrivoltaics, however, can be the caution needed for harvesting of crops, as the solar panels can be easily damaged. Thus, education and expertise are needed when handling the heavy machinery (personal communication, Theuer, 2023). Furthermore, surprisingly, no special treatment is needed for the photovoltaic panels themselves, when compared to conventional monocultural photovoltaics. Maintenance is kept the same, especially in terms of cleaning, as expressed by Janna Hilker (personal communication, 2024), keeping the frequency of cleaning to twice per year.

Within the vertical (bifacial) photovoltaic system however, the issue of uneven light distribution is a day-to-day challenge to be overcome, resulting in heterogeneous plant growth. Although, the benefits of the system will be observed in areas with high winds, where the PV will act as a protective shield.

4.2.4 Rotating canopies

In theory, rotating canopies and elevated panel systems are a very similar concept with a few different details, though the rotating canopies are a more advanced and more innovative version than the latter. The French company TSE is a creator of this type of agrivoltaic, thus is a leading competitor in building the structures; an Innovation Fund project was developed near Somme, in the north of the French countryside, utilising the newly developed technology (European Commission, n.d.), as outlined in figure 15.

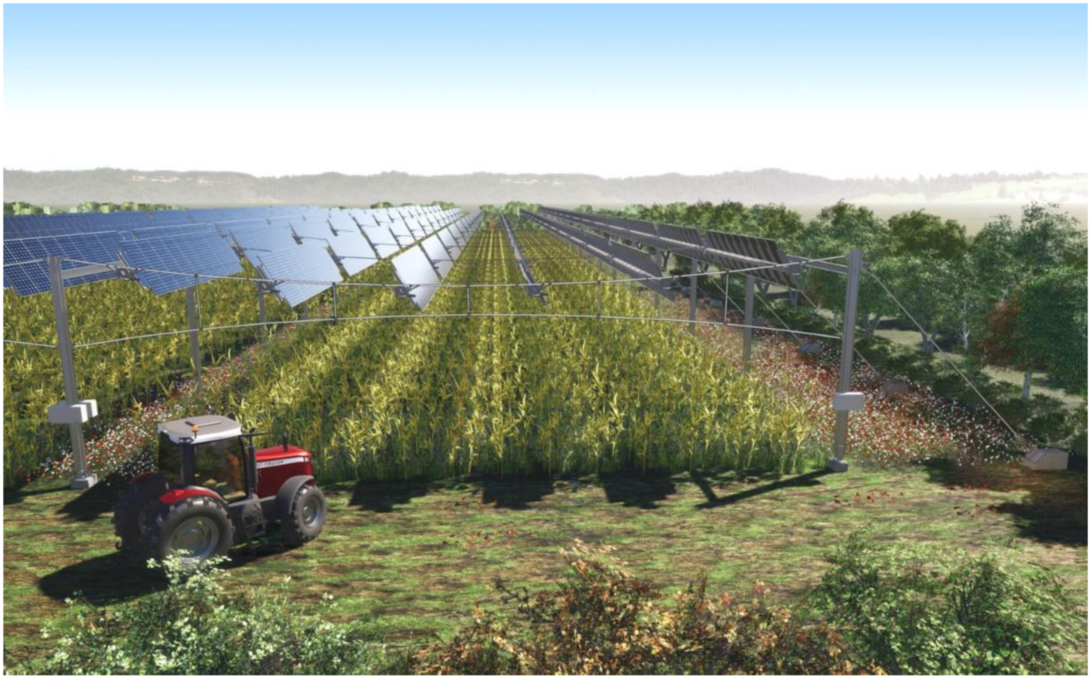

Figure 15: Rotating Agrivoltaic Canopy (TSE, n.d.)

The innovation enables both heavy machinery to move underneath the solar panels as well as the incorporation of rotating bifacial solar cells. Thereby, the harvest of solar energy at all times is possible, while utilising the land underneath for food production. According to Deboutte, the president of TSE, claims that "*our canopy is compatible with all agricultural machinery, including very large vehicles like combines, sprayers and spreaders,*" (see figure 15). The structures on the farms that support the photovoltaics are 5.5 meters in height with a 4-post rigid structure (Deboutte, 2022).

4.2.5 Stilted agrivoltaic structures

The newest technology developed with the first published scientific article on March 4th, 2024, these stilted agrivoltaics have been built in Austria, where the yield output has been measured and compared to that of a vertical agrivoltaic system (for further clarification, see section 4.2.3). The structure of stilted agrivoltaics is made up of solar panels hard mounted at an angle to a rigid overhead metal construction. The structures are built at a minimum height of 2.1m (Krexner et al., 2024) and allow for higher crops, such as corn, as depicted in figure 16, to be planted underneath. Furthermore, it also provides the possibility of heavier machinery entering the land underneath. However, this technology is very similar to that described in 4.2.1 and 4.2.4. However, very limited information is available on stilted agrivoltaics, due to its pristine novelty.

Figure 16: Stilted agrivoltaic (Bím & Neugebauer, 2023)

4.3 Other methods

4.3.1 Grazing pasture

As mentioned above, agrivoltaics used for grazing livestock can be considered slightly controversial, as some countries do not allow grazing and raising animals to be considered as an agrivoltaic system according to Theuer, (personal communication, 22 May 2023) an RWA (Raiffeisen Ware Austria) project manager of an Austrian experimental agrivoltaic farm, for example in the Czech Republic.

As an example of this, Austria's legislation allows for a photovoltaic to be an agrivoltaic as soon as the number of grazing animals reaches 30 individuals per 1 hectare of land. Within Austria, this kind of farming does not provide special subsidies, thus is only part of the tariff, says Theuer. Although, it can be mutually beneficial to have grazing animals on land with photovoltaics, as the desired length of vegetation is controlled.

The most common grazing animals used underneath photovoltaic systems are sheep, requiring little to no management. Besides sheep, though less common, another type of livestock that can be used is poultry, which is relatively easy to manage. Bison and goats are also suitable animals, though need to be managed and monitored closely to prevent damage to the photovoltaic panels (Weaver, 2022).

4.3.2 Ecovoltaics

Ecovoltaics are a technology, borderline an agrivoltaic system, and is another controversial method of realising agrivoltaics, especially in the United States (personal communication, French, January 27, 2024). Ecovoltaics utilise the land underneath solar panels mainly to promote biodiversity, through the management and establishment of native species of plants, as illustrated in figure 17. While photovoltaics can be placed upon land with relatively low values of nature significance, for example degraded land or brownfields, using the "ecovoltaic" approach can be a path towards making the landscape more naturally valuable (Tölgyesi et al., 2023).

While this form of photovoltaic management might not be considered to be an agrivoltaic system in some countries, it is important to note that this sort of management should be practiced across all photovoltaic farms anywhere in the world. Prioritising biodiversity and pollinator populations for the mitigation of adverse effects associated with the implementation of photovoltaics, such as formation of microclimate (Tölgyesi et al., 2023, Armstrong et al., 2016), should be a priority across the world.

Figure 17: Ecovoltaic for promoting biodiversity and pollinator populations (Solarpowerworldonline.com, 2018)

4.4 Agrivoltaics on an experimental level

While agrivoltaic farming is still a very new technology and strategy for land use is on an experimental level, there are farms that are commercially available all around the world, especially in the United States of America. This can be observed primarily in Colorado, Massachusetts, and Maine, according to Boyd (2023). Once again, it is still a very "*nascent business model*" with an overall output of over 2.8GW throughout all of the United States, with most being pastureland and pollinator beds, says Boyd.

Additionally, some countries provide subsidiary payments for the management of experimental agrivoltaic farms, even up to 30% in Austria (Theuer, personal communication, 22 May 2023). Though, the more experimental agrivoltaics will be implemented, the less "experimental" the projects will become, having the possibility to evolve into a more commercial business model, rather than a local project.

This further touches upon the long-lived debate whether to keep agrivoltaics local rather than large-scale and more commercial. This is further discussed in section 4.6.

What's more, as discussed in section 4.1.1. and 4.1.2., Japan has been a pioneer in agrivoltaic development and application, with 1,992 working farms on 560 hectares of land as of 2021. It suggests that it is increasingly popular within the country, and is practiced on a commercial level, also due to the change in legislation with the rapid growth of output of generated electricity.

4.4.1 Agroforestry and agrivoltaics

Agroforestry is the use of trees among fields used for agricultural crop production as well as wood production. The utilisation of fruit trees is preferred to be able to profit from the entirety of the land, though that is up to the preference of the owner and/or cultivator of the fields (Weger, personal communication, 20 April 2023). It has various benefits other than long term cash flow from fruit and wood, such as wind and water erosion mitigation.

Furthermore, within the topic of agrivoltaics, agroforestry is often referred to in order to communicate the effects of shade on the crops underneath. This is done to be able to compare the effects of photovoltaics and the shade they will cast onto the crops. This is exemplified within one of many studies: "Agrophotovoltaic systems: applications, challenges, and opportunities. A review" (Weselek et al., 2019). The authors point to significant cash crops, such as coffee, blackberries, or blueberries to benefit from the shade provided by the trees.

However, the goal of this discussion is not to be about the comparison of shade effects on crops, but rather, it is to highlight the unknown project that combines agroforestry and photovoltaics in Průhonice, Czech Republic. The project is developed by the VÚKOZ (Výzkumný ústav Silva Taroucy pro krajinu a okrasné zahradnictví, v.v.i.) institute and is in the early stages of development, with only around 2 years of running experience. The aim is to implement agroforestry, as described above, but further increase the efficiency of the land by implementing photovoltaic modules among the individual trees, as shown in figure 18). What's more, the solar panels that the institute is testing harbour a tracker system, to follow the sun and thus produce the highest amount of electrical energy possible, given its disadvantageous position underneath trees.

Figure 18: Agrivoltaic implemented in agroforestry, VUKOZ Průhonice, Czech Republic (Weger, n.d.)

Although this project is extremely creative and purposeful in utilising the land as efficiently as possible, the question whether this could realistically be a commercial agrivoltaic remains unanswered. Due to the shaded area in which the photovoltaics are mounted, it is questionable whether this would be a profitable investment on a larger scale. However, in personal communication with Dr. Weger, it has been highlighted that agrivoltaics would be more suitable to be kept as a local and private commodity. For further information, refer to appendix 10.2.

4.4.2 "Aquavoltaics" or "Floatovoltaics"

Aquavoltaics or "floatovoltaics" are a concept, less practiced than regular agrivoltaics, that puts photovoltaic panels on top of waterbodies, such as lakes, ponds, reservoirs, or fisheries, as evidenced in figure 19. It combines photovoltaics and the production of fish populations meant for food consumption. A fraction of the surface area of a waterbody is used to have a dual and effective purpose, due to its "unused" potential (Pringle et al., 2017). Essentially, it combines floating photovoltaics and aquaculture.

Figure 19: "Floatovoltaic" in Windsor, CA - "solar pond" (Collins Electrical Company INC, n.d.)

As Pringle et al., (2017) indicates, the potential of scaling this concept is both for commercial aquaculture farming, as well as for private use; off the grid areas, where a "floatovoltaic" farm will guarantee both a clean energy source and a sustainable (if practiced accordingly) food source underneath. Thus, it can be argued that this technology is more suitable for local and small-scale use to ensure the sustainability of the project, avoiding the unsustainable concept of large-scale aquaculture farming that is practiced all around the world (Azad et al., 2009). Large scale farming rises concerns from the environmental point of view, especially when considering the loss of habitat for native animal species, such as mangroves or wetlands (Azad et al., 2009).

An example of an "aquavoltaic" is a rather new "floatovoltaic" in Windsor, United Kingdom, as depicted in figure 19. The project has implemented the solar modules as a part of a waste reclamation facility, which will, according to Collins Electrical Company (n.d.), save up to 80 percent of the facility's energy requirements.

4.5 Is it realistically possible to grow crops underneath or around an agrivoltaic?

This question is likely to arise for individuals who have recently become acquainted with the notion of “agrivoltaics”. It stems from the non-avoidable fact that having a solar panel in an agricultural field will result in the creation of shade. Yet, over the past few decades, there have been numerous studies conducted studying this very trend, and it has become apparent that it does not necessarily have to be the case.

Most of the concerns arise from the reality that the solar panels cast a shadow over the crops, possibly leading to stunted growth; thus, lower yields of produce would be expected after the harvest. Yet, many studies have overcome this issue by the use of “mobile panels” (movable arrays of solar modules on a similar structure as seen in Figure 8,9 and 11), as Marrou et al. (2013) indicates. The technology enables the penetration of solar energy through the created spaces between to support the growth of plants in their early stages of growth and development.

As Jo et al. (2022) suggests in the scientific article “Comparison of Yield Components of Several Crops Grown under Agro-Photovoltaic System in Korea”, some species planted underneath an agrivoltaic system, such as rice, onion, garlic, rye, soybean, adzuki bean, monocropping corn, and combined soybean with corn could benefit. Further, some shade tolerant crops, such as lettuce or cucumber have also been monitored. The outcome suggests that there was not any indication of negative impacts on the growth of rye and corn over a testing period of 2 years, and the combined planting of soybean and corn has become beneficial in yield mass. Furthermore, the shade-tolerant crops have proven to benefit from the shade under the photovoltaic, thus have a synergistic relationship.

It is important, however, to consider the productivity and safety of the photovoltaic itself as well. The photovoltaic panel needs to be considered, because as soon as one module is faulty, it can hinder the output of energy production of the entirety of the farm. This phenomenon can be seen especially in agrivoltaics because the same hindrance can happen with shading of the solar panel, as was explained in personal communication with Petr Klimek (2024). Furthermore, caution and education of workers is highly needed because the solar panel is always under electrical current when being exposed to sunlight. Moreover, fires, electric shocks, and electric arcs must be taken into account when planning the agrivoltaic as well, due to the presence of plants under/and or around the agrivoltaic and humans that will be managing the farm (personal communication, Petr Klimek, February 29, 2024). Safety is often an overlooked factor, which is in fact the most important factor that demands attention at a solar farm, providing a safe working environment. Thus, proper education needs to be provided to avoid harmful situations.

Furthermore, since agrivoltaics are a combination of energy harvesting as well as food or crop production, the yield of crops should not be considered as the only factor. The energy production output should be an additional factor and these two should be added together to count the overall output (Weselek et al., 2021)

4.5.1 Microclimate of an agrivoltaic farm

The incorporation of solar panels into a landscape is a big change to the local environment and ecosystems. Thus, it is expected that the microclimate will be changed as well. An observation could be made within the negative growth trend with sun-intensive plants. However, as Weselek et al. (2021) indicates, in some weather conditions, the presence of the agrivoltaic could prove to be beneficial. The microclimatic effect in agrivoltaic construction can be one that is a decisive factor of the scale at which the development will take place and how future legislative directives will take course. Further exploration and research still need to be undertaken to fully understand the full scope of the effects that agrivoltaics have on the microclimate. Although, multiple studies have shown that agrivoltaics are beneficial within areas with hot and dry weather conditions, offering cooling effects for the plants through supporting growth (Williams et al., 2023). A study, by Weselek et al. (2021), aiming to assess the changes in microclimates within an agrivoltaic system, has been conducted close to Lake Constance in Germany, with a testing period from 2016 to 2018. It has demonstrated various trends, confirming the existence of a microclimate resulting from the application of an agrivoltaic system. Furthermore, the capacity of photosynthesis has reduced by up to 30%. As indicated by Weselek et al. (2021), soil temperature decreased beneath agrivoltaic systems during the summer months as an outcome of a lower amount of penetration by solar radiation. Additionally, agrivoltaic systems were associated with lower soil moisture and air temperatures, along with a modified distribution of rainfall. "*Furthermore, in both years, the plant height of all crops showed an increase under agrivoltaic conditions*."

The most important piece of information gathered, however, was that when the environmental conditions are not ideal for plant growth – extreme temperatures and drought conditions, the agrivoltaic might affect the plant growth in a positive manner. This is exemplified in the planting of winter wheat and potatoes in 2018 (a very unfavourable growing year due to hot weather and dry conditions), the yield was increased by 2.7% and 11%.

Another case study conducted at the University of Arizona, which has tested the effect of the microclimate on different pepper species, found that the photovoltaics created an environment with milder temperatures during the daytime, preventing harsh sunlight to damage the plants and warmer temperatures during the night. Likewise, their results suggest that the yield of chiltepin pepper production was three times higher than average, compared to yields that were produced under regular shading structures (Barron-Gafford et al., 2019)

Thus, even if some plants might not benefit from the positioning underneath an agrivoltaic in normal conditions, it has been proven that the plant can benefit from its presence in extreme weather conditions. Similarly, as the planet grapples with extreme weather phenomena each year, such as drought, the implementation of AV (agrivoltaic) systems could indeed prove beneficial in increasing yields, primarily in the most vulnerable countries. The countries facing the highest risk of being affected by climate change and global warming are, according to the UNFCCC (Unfccc.int, 2021), are low-income countries (LICs) and Small Island Developing Countries (SIDS).

4.6 Small-scale or large-scale agrivoltaic projects?

The concept of whether to keep agrivoltaics small-scale or large-scale projects is currently dependent on the investors and developers. However, researchers have raised concerns regarding implementing this technology on a large-scale basis (personal communication, Janečková, 2024, Weger, 2023). This is due to concerns both from the perspective of microclimatic impacts as well as the monocultural implementation of photovoltaics, without sustainability-driven targets.

It can be argued that from a certain scale, the agrivoltaic project will become once again monocultural. However, this is all dependent on the mode of cultivation of the field, mainly whether more species of crops are planted or whether solar panels are merely erected among or above a monoculturally managed agricultural field. The concern lies within taking a different approach to both farming and generation of electricity as a whole. Collective action towards a sustainable development and alternative approaches to conventional practices must be promoted.

Thus, the question of scale is very much dependent on the intention of managing the area, and this ideology should be implemented within legislative frameworks. With that in mind, caution still should be taken when implementing agrivoltaics on a larger scale, as microclimatic (for further information, see section 4.5.1) conditions could have a major impact on the surrounding ecosystems. Accordingly, it should be recommended that small-scale and mid-scale projects are preferrable, and large-scale projects should be very hard to implement in terms of directives.

4.7 Case studies in Austria

A fieldtrip was undertaken to two different agrivoltaic farms within Austria in May of 2023, with the objective of further and detailed learning about this innovative technology, given its general absence in the Czech Republic.. The first farm, an agrivoltaic orchard and field, was developed by the RWA corporation in Pöchlarn, Austria; the second is focused on the implementation of vertical solar panels and the farming within the space between them, carried out and managed by the University of Natural Resources and Life Sciences in Vienna. All following information has been communicated personally as a field trip of personal interest, where it was possible to interact with the individuals involved within these projects.

4.7.1 RWA Experimental agrivoltaic

According to personal communication with Daniel Theuer (May 22, 2023), the project manager of RWA, which is done in simultaneous partnership with Cemix, a sister company of RWA. This project involves three agrivoltaic testing areas, each with a different crop and purpose; in total, however, the entire AV system covers approximately 1000m^2 with a production of 50kW.

The agrivoltaic of most interest is an overhead photovoltaic system, as depicted in figure 13, with the above-mentioned roof-like structure above the crops. This photovoltaic system implements semi-transparent solar modules that filter out approximately 50-60% of sunlight, creating lower water evaporation rates. The production output of the photovoltaic has been measured to be approximately 70% of that of a normal PV plant.

Furthermore, the crop of choice is apple trees, with a control photovoltaic that applies nets, to compare and differentiate yield outcomes. Though, it has been clarified that it would have been possible to plant wine, berries, and hops (though it is necessary to monitor plant height in hop plants). The distance that has been applied among the rows is 3 meters, disabling the entrance by machinery; manual harvest is thus needed to take place. In addition, using photovoltaics in this case offers other significant benefits. The energy generated can be used for crop irrigation, which reduces costs. It has also been observed that the use of fungicides decreased due to a reduction in moulds, as the plants are protected from precipitation.

Secondly, another type of experimental agrivoltaic farm in use are tracker solar panels with a single tracking mechanism, thus following the sun throughout the day. This is used in combination with 9-12m rows of field in between, allowing the use of machinery. Additionally, this space is open to students of agricultural programmes to test the area. The promotion of biodiversity is through the growth of native plants directly around the photovoltaic, allowing for pollinators to enter the micro-ecosystem.

Lastly, the implementation of sheep has been applied underneath photovoltaics within the same parcel. However, it must be noted that this construction covers most of the area, allowing for the animals to graze for longer periods of time. A reduced need in the rotation of the cattle among different properties is thus enabled.

It is necessary to note, that all the above mentioned agrivoltaic systems, are in fact registered as an agrivoltaic, yet each receives different type of funding. Thus, as Mr Theuer describes, the most innovative and extra-experimental AV systems (such as apple farming) receive an additional subsidy, while the grazing of animals merely covers a part of the tariff.

4.7.2 Agrivoltaic with vertical solar panels in Vienna

According to personal communication with Dr. Wagentristl (May 23, 2023), the experimental agrivoltaic system on the outskirts of Vienna and owned by the Viennese government, is a farm that employs vertical solar panels with space in between for planting produce, as seen in figures 9 and 14. The establishment of this farm took place in 2021, and the initial year was dedicated to recultivation, with alfalfa being introduced across the farm for this purpose. Thus, as of May 2023, when the site was visited, there has been only one harvest in 2022. Moreover, the entirety of the farm is registered as an ecological farm, operating without additional artificial pesticides and minerals. A control farm has been set up in a different location, applying the same mechanics and crops, with the difference of the absence of solar panels.

This agrivoltaic system is managed and experimented upon by the students at the University of Natural Resources and Life Sciences in Vienna, and the aim of the project is to determine the rain and shade effect of solar panels on the quality and quantity of produce grown. Another goal is to reach maximum biodiversity with the implementation of biodiversity strips directly underneath the solar panel construction. An increased number pollinator insects and the increase of biodiversity in an agricultural setting with no pesticides (the biodiversity strips can be seen in figure 9) is another target. The maintenance of the biodiversity strips in combination with the photovoltaic is simple; the plants are hand-picked twice a year to achieve a controlled height.

Even with the application and planting of crops, such as soya, the overall outcome of the solar panels have come to around 85% of a normal photovoltaic. The advantage of operating a vertical agrivoltaic farm with field space is the ability for machinery to be employed, though it is necessary to aim for caution to avoid causing damage to the solar panels. In order to reach the highest level of protection during the harvest, the photovoltaics are covered with protective materials, and the machinery is configured to work at the minimal setting.

The crops tested within this innovative AV system as of yet, are alfalfa, barley, soya and winter wheat. A crop rotation style of agriculture to promote soil health is employed. The abovementioned reference and control fields, have, in addition, been testing corn and pea yields. Furthermore, from the current analysis, the quality of produce has proven to be the same when weighed against a reference field, though the yield quantity differences cannot be concluded as of yet, due to the lack of data, as the agrivoltaic is still in its early stages.

PRACTICAL PART

5 Methodology

This study aims to explore the scalability of agrivoltaics as an alternative to monoculturally managed photovoltaic farms. This research adopts a qualitative methodology, through conducting individual interviews with field experts to gather insights on their perspectives. Given the novelty of agrivoltaics, the interviews were chosen to leverage their first-hand experience and expert judgment, offering a unique apprehensive approach to their scalability.

As detailed below, the interviews will be carried out in an online setting. The estimated length of the meetings is 20-30 minutes, using a predetermined set of questions (detailed in sections 5.2.1-5.2.10) for a structured discussion. A transcription of each interview will be made, with distinct permission to be used in this research from all interviewees. All the meetings will adhere to ethical standards, ensuring informed consent on how the results will be obtained and their inclusion in this thesis.

Transcriptions will be utilised to count keywords relating to factors that affect the scalability of agrivoltaics. A pattern will be identified and discussed later in the thesis.

5.1 Gathering interviewees

Firstly, it is crucial to find individuals, who are both experts as well as entrepreneurs and environmentalists, to interview on the topic of agrivoltaics. The key is to determine the appropriate number of recipients, who are willing to undergo the interview process. Within this particular research, it was determined that the number should be kept under 10, as there could be too many differing opinions, thus creating a difficult task of picking too many keywords later on in the research. It is necessary to contact companies operating outside the Czech Republic, especially those with legislation regarding agrivoltaics. Furthermore, another useful source are formal excursions of agrivoltaics, such as a visit to Austria, as described in sections 4.7.1 and 4.7.2. Within this research study, people were gathered from both the Czech Republic, as well as other countries within the EU.

The agrivoltaic experts interviewed in this research were DI Mag. Daniel Theuer (Austria), Sophia Melcher (Austria), Ing. Jan Weger Ph.D. (Czech Republic), Ing. David Hájek Ph.D. (Czech Republic) and JD, LLM Dan French (United States of America). The other individuals interviewed, like entrepreneurs, environmentalists or professors and other people of reference: doc. Ing. Kristina Janečková, Ph.D. (Czech Republic), BSc Margarita Samsonova (Latvia).

Most of the interviewees were contacted via email, telephone communication, or through personal communication. Furthermore, Mr. Dan French was contacted through the Solar Farm Summit profile on the social media platform LinkedIn.

5.2 Creating interview questions

The curation of interview questions, specifically designed to gather perspectives on agrivoltaic feasibility, is a necessary step for identifying key obstacles. 10 individual questions were created; each uniquely formulated for the topic of this study, to rule out the peripheral factors. Sections 5.2.1 - 5.2.10 outline the questions chosen and the reason for the choice and composition.

5.2.1 Question 1

What is your background in agrivoltaics or photovoltaics, and what is your current work in that field? Or have you visited an AV farm? Where was it located? Do you know of any others who are doing this?

The aim of this question is to gather information on the respondent and their experiences or knowledge within the field of agrivoltaics, as well as the knowledge on photovoltaics. Furthermore, its primary objective is to get a better and clear background on what perspectives and opinions, as well as personal work is being done by the interviewee.

5.2.2 Question 2

If you were interested in building an AV, would you be hesitant, why?

This question encourages the interviewee to identify what they believe to be the most crucial factor that affects the construction of agrivoltaic projects. It can also act as a prompt for considering it in a more individual perspective, taking into account their country's legislative measures, as well as the possible political circumstances or even the given climate. The aspect of being hesitant can reveal the knowledge about agrivoltaics, and even provide solutions for improvement of current design flaws of the technology.

5.2.3 Question 3

How do the factors affecting the scalability of agrivoltaics vary across different regions and climates?

The determination of aspects of different regions and climatic effects is enabled through this question. Each specific region presents opportunities as well as barriers, thus having several interviewees from various parts of the world provides a better overview and outlook. Moreover, while identifying the differences from all around the world, it also recognises the barriers of implementing projects at different scales. Thus, provoking thought about whether small-scale or large-scale use is suitable. By determining the factors involved in applying agrivoltaics in various regions, a clearer insight is gained about actions needed to ensure an ideal fit for each project.

5.2.4 Question 4

Do you believe that crop yield is increased, decreased, or has no change because of AVs?

This inquiry aims to delve into the results that some of the interviewees have obtained from their experimental projects or scientific research. Thus, this is another form of research through obtaining results that have not been released in any official scientific publications. For the other interviewees who have not been involved in any research surrounding agrivoltaics, it invited the interviewees to critically consider the opportunities, given all the possible factors affecting crops under or around photovoltaic panels.

5.2.5 Question 5

What are the economic and environmental benefits of agrivoltaics compared to monoculture photovoltaics?

The aim of the question is to "set the stage" and inquire about the interviewee's position, to be able to determine the overall benefits of applying agrivoltaics as an actual equal alternative to general photovoltaics and to identify its benefits. In preparation for the following question 5.2.7, where the possibility of integration of photovoltaics into already existing environments is presented, possibly incentivises the interviewee's mind to adjust to the idea of the overall general application of the innovation.

5.2.6 Question 6

What are the challenges associated with the adoption of agrivoltaics, and how can they be addressed?

In essence, the topic corresponding with 5.2.2, though gives incentive to delve deeper into the challenges associated with the implementation of agrivoltaic systems. Furthermore, another opportunity is presented to express and further develop the answers, after being given the chance to address other aspects of agrivoltaic systems and their global scalability. Incentive is provided for the respondent to critically address the challenges and think about the modes of tackling them. Subsequently, potential creativity and potential advancement and development of the technology can be assessed.

5.2.7 Question 7

How would you say agrivoltaics can be integrated into existing agricultural systems?

Since agrivoltaic systems usually aim to be constructed on agricultural land or farmland, the aspect of implementing agrivoltaics into an existing ecosystem has to be considered, even if this is a possibility of the future. A major change would be posed within the ecosystem and environment, and the input from the experts is needed to assess the extent of this possibility or if this is even a possibility.

5.2.8 Question 8

What are the future prospects of agrivoltaics, and how can they be improved?

This innovative technology is driving change, and the market value is ever so increasing, as discussed above. In combination with its sustainability outlook, it can be predicted to have a large impact on both the sustainability development and use of land. Thus, the opinion of both experts and environmental experts is needed for an identification of its true significance and thus its future, opportunities as well as the benefits. Furthermore, considering the possibilities or restraints, further research might be applicable and advised.

5.2.9 Question 9

What would you say are the most limiting factors currently affecting the scalability of AVs, both on a national and international scale? a) Financing (investors) b) Climate c) Interest d) Legislation e) Something else (explain)

The proper identification of the most significant challenges that currently act as the biggest barriers in terms of the scalability of agrivoltaic systems, is enabled. Moreover, while interviewing field-experts, the answers to this question provide invaluable insight into hands-on challenges within the real world that may differ from farm to farm. While interviewing the experts, the experience is crucial to be assessed and considered. Furthermore, those with extensive knowledge and experience with applying such projects, have a bigger scope of insight.

5.2.10 Question 10

What are the situations or conditions where you feel that AV would not be effective and why?

By asking this, a reference is made to where the agrivoltaic technology would be unsuitable and or unapplicable in its entirety, thereby revisiting the idea of "to what extent is it scalable" on both the national and international levels. Henceforth experts have the possibility of its identification and sparking discussion within the field itself.

5.3 Conducting interviews

The conduct of the interviews must take place in an online setting. It is most practical, as some individuals are in different countries or continents than that of the author of this thesis. Therefore, the "Google Meet" was the chosen platform. It it is an accessible, free, and reliable online meeting platform, an ideal medium for the interviews.

Furthermore, the interviews are to be transcribed, to gather all the information said within the interview and be able to refer to it at a later time. The online website "laxis.com" was chosen; it is a browser extension which allows offers transcripts of online meetings. It further enables the user to download it as a word or pdf document. However, the transcriber has a major flaw – it is unable to recognize some words. Therefore, personal correction and enhancement of the downloaded documents is necessary for text clarity and understanding.

Moreover, due to the open-ended nature of the questions above (sections 5.2.1-5.2.10), the summary of each of the interviews will be provided, as each interview has a slightly different outcome. This is because all the people come from different parts of the world and have different perspectives on the matter at hand.

5.4 Keyword categories

Since the interview questions were designed to outline the most prominent factors that affect the scalability of agrivoltaics, it is possible to choose a few relevant factor groups that are recurring within and among the interviews and their transcripts. However, this is to be done after the interviews and after the correction of the transcript documents.

Some keywords that might apply are, for example, the factors mentioned in section 4.2.9, like financing (investors), legislation and so on. However, multiple keywords might be chosen for one singular keyword category, given that they have the same or very similar meaning, for example: Category of legislation might apply for these words: legislation – policy – regulations - rules, or category of finances: finances – investors – investment – financially.

This research study has chosen these keyword categories that represent the factors affecting the scalability of agrivoltaics:

- **Legislation** – legislation, legislative, regulations, regulatory, frameworks, framework, permission, permissions, permit, permits, permitting, policy, policies, rule, rules, law, laws, legislator, approval, approve.
- **Farmer** – farmer, farmers, landowner, landowners, owner, owners, maintenance, cooperation.
- **Technology** – technology, technologies, technological, innovation, innovative, optimize, optimization, robotisation.
- **Knowledge** – knowledge, knowledgeable, education, educated, research, experienced, experts.
- **Politics** – politics, political.
- **Planning** – planning, landscape, land use, farmland, government, governmental.

- **Stakeholders** – community, public, stakeholders, locals, communities, public, acceptance, "nimb" (not in my backyard), "nimbing".
- **Economy** – economy, economical, economic return, economic.
- **Finances** – investment, investors, financial, financially, finances, finance, money, monetary, profit, profitability, profitable, financing, expensive, insurance, insurer, insurers, subsidies, subsidy, costs, income, grants, capital, funds, funding, loan, loans.
- **Climate** - climate, physical, weather, hot, sun, extreme weather, extreme temperatures, warm, warmer, sunny, solar radiation, climate warming, droughts, sunlight, climate change, sunshine, radiation, dry, desertification, floods, hurricanes.
- **Interconnection** – grid, interconnection, utility.

5.5 Determining the number of keywords with ChatGPT3.5

ChatGPT-3.5 is a conversational artificial intelligence platform, which was developed by the company "OpenAI", and is designed to have a coherent conversation with its users, providing information about desired queries.

Within this research study, ChatGPT-3.5 is used to count the number of keywords appearing within the transcripts and providing an output in the form of a table. The table will contain the keyword categories and the corresponding numbers of uses within each transcript.

This information will be utilized within a Microsoft Excel to create multiple tables with this information among transcripts, as well as one with the information altogether. The text in appendix 10.1. specifies the prompt used to generate results.

Afterwards, if the software understands the prompt, it will ask for the transcript, and hopefully provide the table with the appropriate results.

However, since this technology is still in its early stages and not perfect, there is a high likelihood that this method for counting the keywords will be faulty and the software will not be able to complete the task assigned. Many factors might influence this, such as the length of the transcript. Each interview was estimated to take approximately 25-30 minutes but possibly even more; thus, each transcript is at least 3 pages long on average. Hence, some interviews might be longer, spanning to possibly 6 or more pages. In turn, the possibility that they will be unable to be processed might be very high. In such case, the keywords and the categories will then be counted manually directly from each transcript, and then marked into an excel document.

5.6 Graphical representation

Using the information within the Excel table that has been put together within section 5.5, a pie chart, as well as a conventional bar graph will be created. The diagram will contain the categories tested utilizing a visual representation for the most frequently used keyword categories.

A graphical representation of both the most prominent category will be used, but also a representation of the distribution of answers among different interviews.

6 Results

Following the outlined methodology, this chapter presents the findings from the interviews conducted, which highlights the key data and key categories which affect the scalability of agrivoltaics the most. The results include the summary of individual transcripts to be able to perceive the difference in perspectives among different individuals based on their background and work. In addition, a graphical representation of keyword frequency, will also be included.

6.1 DI Mag. Daniel Theuer from Raiffeisen Ware Austria (RWA)

Mr. Theuer is a project developer within RWA (Raiffeisen Ware Austria AG) Solar Solutions for nearly three years, a company that has implemented an agrivoltaic project in Pöchlarn, Austria (see section 3.6.1). His original background is in electrical engineering and has worked in the renewable energy industry, initially in North America and Europe and now his focus lies within Central and Eastern Europe, developing solar projects.

The approach, being from an experienced member of the development team in Pöchlarn, is a very optimistic one, as positive results have been observed. However, he recognizes the need for proper legislation and policy making for these innovative projects to be applied in the field. Furthermore, financing and investment is a key component for the success of this technology, while farmers also need to express interest. Overall, his perspective on agrivoltaics is one of seeing the benefits over monoculture photovoltaics, but focus lies within the funding component, as well as stakeholder involvement.

6.2 DI Sophia Melcher from Raiffeisen Ware Austria (RWA)

Ms. Sophia Melcher is a project developer at the RWA agrivoltaic project in Pöchlarn, Austria. She was involved in the decision-making process of the project, which has provided invaluable insight. She has extended more detailed information on studies conducted on RWA's agrivoltaic project site. Being the front-lead on the project, a significant increase in yield of winter wheat, up to 14% has been noted and shared.

Working together with Daniel Theuer, the view on financing is fairly similar, and hence it was concluded that limited access to funding and financial support might be the most limiting factor hindering the access and scalability of agrivoltaics, due to the higher upfront costs and initial risk of investment and return of costs. Nevertheless, it was noted that stakeholder, farmer and community involvement and education is a key component, because farmers will be the most targeted group of people that will be incentivised to adopt agrivoltaics.

6.3 Ing. Jan Weger Ph.D. from the Research Institute for Landscape and ornamental Gardening (VÚKOZ)

Dr. Weger is a researcher and doctor of environmental sciences who has worked at the Research Institute for Landscape and ornamental Gardening in the Czech Republic, and with a background in biomass production research. Additionally, he has been a researcher within an agrivoltaic project that links both agrivoltaics and agroforestry (see Figure 14) for the past few years in Prague.

Within the interview, it was repeatedly mentioned that he mainly supports the local and small-scale development of agrivoltaics and thus renders large-scale development unsustainable. Similarly, his vision of the main problems that affect the spread and scalability of agrivoltaics is the restrictive legislation lack of policies in the Czech Republic. Topics regarding large-scale investment into fields by large corporations have been discussed, and the biggest problem within the field could potentially be the promoting of agrivoltaics through substantially enormous subsidies, and the cause of an agrivoltaic boom, which could have very bad consequences for the sector. Based on the assumption that poor planning could be implemented within the hypothetical conditions, culminating in side-effects, such as improper use of shade-tolerant crops. Lastly, in his opinion, agrivoltaics are a perfect fit for implementation in the Czech Republic, due to its suitable weather conditions.

6.4 Dan French, JD, LLM from the Solar Farm Summit

Mr. French is the executive producer of the largest North American summit "Solar Farm Summit" focused on conferences and exhibitions of agrivoltaics and everything about this new innovative technology to promote it, especially in the United States of America. His original background is in the law; being an attorney has shaped his view in the world of innovation, and further helped him in his later professional endeavours. Before initiating the summit on agrivoltaics, his focus were brownfields and conferences dedicated to discussing them.

His perspective on agrivoltaics is somewhat different due to the difference in agrivoltaic practices in the USA compared to the European standards. Overall, agrivoltaics in the USA are currently focusing on promoting biodiversity and insect populations by planting native species underneath solar panels, as well as grazing of livestock underneath, rather than crop plantation and cultivation.

His view is visionary, seeing the full potential of this technology as an opportunity for combatting climate change anywhere in the world, especially the effects of desertification and overall climate change. Though he does mention the hurdle of lack of access to the grid, as large areas within the United States are often out of reach, which needs to be a priority in implementing agrivoltaics in the future. Along with extremely long periods of time for legislative procedures to take place, interconnectedness of the electrical grid are the most important factors to keep in mind when planning an agrivoltaic, thus affecting its potential and scalability.

6.5 Ing. David Hájek Ph.D. from the Research Institute of agricultural engineering in Prague

Dr. Hájek is a researcher from the "Research Institute of agricultural engineering in Prague", and is working on a small-scale agrivoltaic project, while being in close contact with other companies and institutions focused on the topic of agrivoltaic research and innovation of this technology. He sees the potential within this technology as one of automation, robotisation and precision agriculture.

Yet, the legislation and regulations are still very restrictive in terms of being able to apply this technology in a real life setting in the Czech Republic. Not to mention, due to the financially demanding nature of agrivoltaic projects, this will pose as a tremendous barrier in being able to spread this technology and interest the farmers that would eventually be incentivised to practice this technology on their farmland.

Spiking interest in the target consumer – the farmer, will be somewhat of a challenge. To solve this problem, it will be necessary to cooperate with state ministries of countries, further research and publishing of promotional and scientific articles.

6.6 doc. Ing. Kristina Janečková Ph.D. from the department of landscape and urban planning, ČZU

Dr. Janečková is an associate professor at the department of landscape and urban planning at the Czech University of Life Sciences and is teaching the course of landscape planning, landscape management, landscape history and working in practice on projects in the same areas. Her connection to agrivoltaics is not direct, though she has been a consultant on some agrivoltaic projects referring to their effect on landscape character.

She shares her opinion with most of the other interviewees, one of keeping this technology more localized rather than large, commercialized areas. Her reasoning for this is that the microclimatic effects of this innovation will be affecting other forms of wildlife and biodiversity.

Although, the biggest problem will be the land use and landscape planning for this, as there is still not enough legislation, especially in the Czech Republic. Overall, theoretical applications are easy to plan, though the planning in reality for such projects may become complicated, which often leads to its resolutions through the means of monetary assets and or financial support.

6.7 BSc Margarita Samsonova, United Nations (UN) sustainable energy ambassador

Ms. Margarita Samsonova is a wildlife conservationist and entrepreneur dedicated to helping environmental organisations, institutions, and companies to reach their full potential on social media platforms through her social media company “Behind the Greens”. Last year, she has been selected as a UN sustainable energy ambassador and has been very interested in the topic of renewable energy sources.

Being a wildlife conservationist, her biggest concern lies within the effect of agrivoltaics on wildlife populations, behaviour, and breeding trends. She, like many of the other interviewees, would like to see agrivoltaics implemented as a part of localized projects, rather than on a large-scale, commercial basis. She argues that the land needed for such large-scale projects would require the destruction of natural habitats, biodiversity and cause the further eradication of wildlife.

Notably, the main area, which she believes, that affects the spread and scalability of agrivoltaics is the lack of expertise, experience, education, and knowledge within this field of study. More research and studies are needed to assess the potential effects of this innovation on wildlife and its behaviours.

Nevertheless, her opinion is not all negative in terms of this new technology; she believes that agrivoltaics have great potential and due to their dual-use nature, are a perfect addition to the world of the future. Though her message is to take caution when implementing these new technologies and innovative projects.

6.8 Graphical representation

The graphs below identify the most prominent factors, or the most mentioned topic categories within the interviews that affect the scalability, barriers and spread of agrivoltaics.

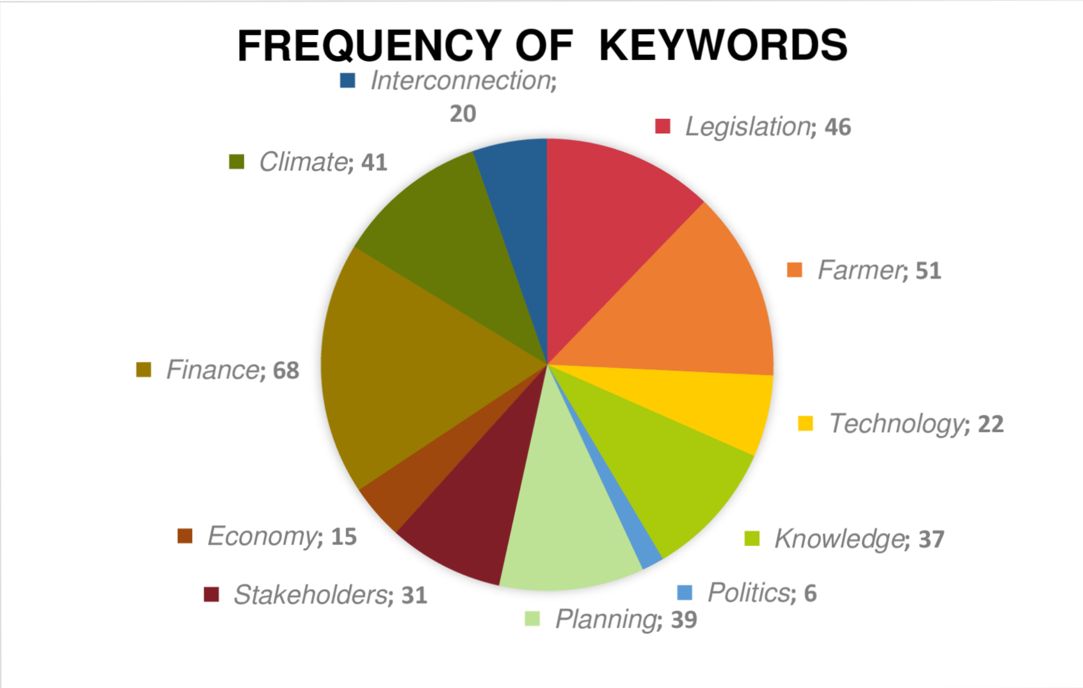

Figure 20: Pie chart representing the most mentioned word categories within interviews with field-experts.

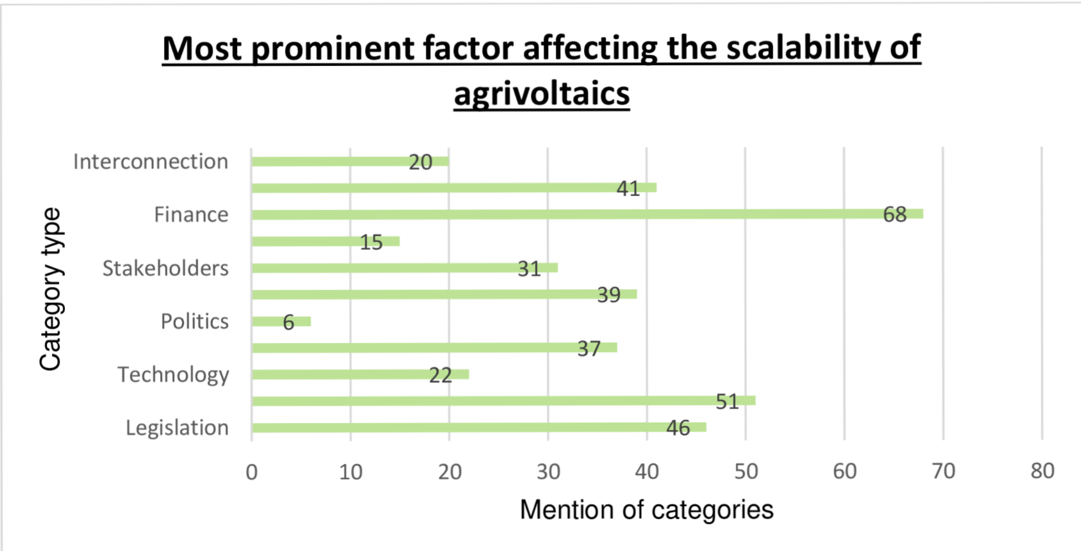

Figure 21: Graphical representation of most mentioned barrier categories in interviews.

As shown in Figure 20 and 21, the most notable factor that stands out and received the largest amount of attention was the topic of financing the agrivoltaic projects, with 68 mentions across all interviews. The next most mentioned category is “the farmer” or the interest of these individuals to pursue the technology.

As can be observed in both Figures 20 and 21, the least discussed barrier category is politics, being mentioned only 6 times, as well as the economy, appearing 15 times within the interviews. Albeit important, it is necessary to mention that all these factors-barriers affecting the scalability of agrivoltaics, are important. They still act as a barrier to being able to build agrivoltaics.

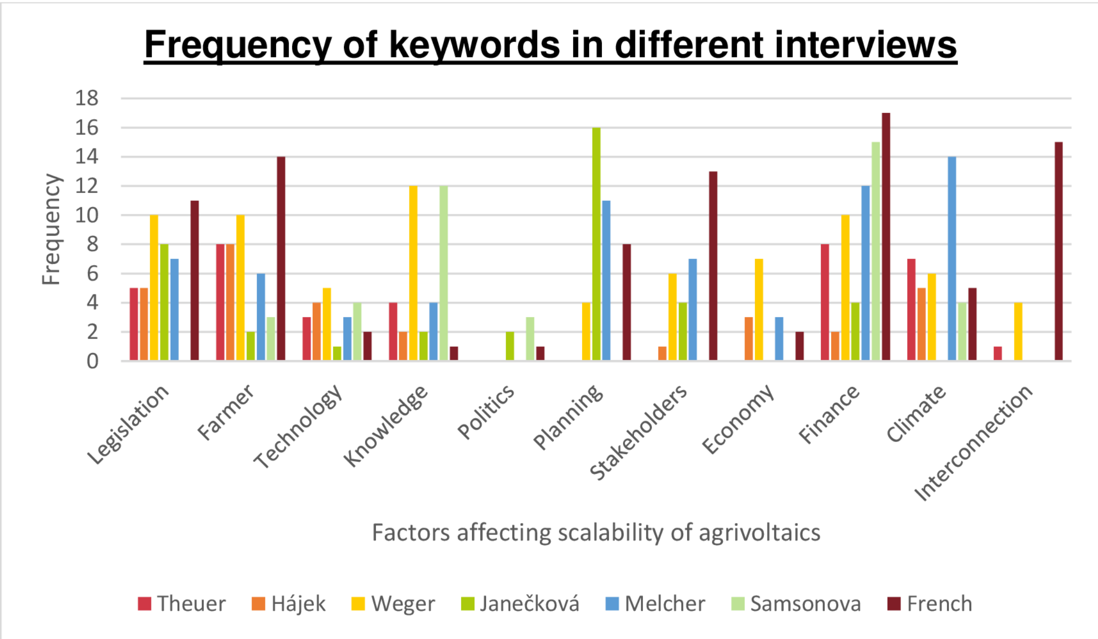

Figure 22: Keyword category distribution among interviews.

In addition, taking into account that interviews were conducted with different field-experts, from both the developer, researcher and entrepreneur perspectives, everyone’s responses were slightly different. Figure 22 represents the distribution of keyword categories and their utilisation among the different interviews. For example, as shown in Figure 22, a landscape management expert, Dr. Kristina Janečková, has been the leading advocate within the “planning” category, while Mr. French, originally an attorney highlighted the category of interconnection and finance.

In contrast, it is visible that the category of “politics” has received the least amount of attention from the interviewed individuals, with “economy” second to last. Furthermore, a surprising element within the results has proven to be the one of stakeholder influence over the construction of agrivoltaics. This category was expected to be more numerous in comparison to the others.

Through these visual representations, it is clearly noticeable which categories have been mentioned the most among interviewees, regardless of the individuality of the interviews conducted. Moreover, this also represents a more international overview of the barriers as well as prospects of the implementation of this new technology, due to the fact that each background and nationality of the individuals is very different. What's more, due to this, the perspective provided through the personal communication with Mr French has been broadened; the practices, legislation and conditions vary, and with that the possibilities and opportunities in the adoption of agrivoltaics.

7 Discussion

This thesis research addresses the scalability of agrivoltaics as an alternative to monoculture photovoltaics, a critical issue in the ability to implement a dual-use technology in the landscape while promoting biodiversity. Despite the extensive research on the effects of shading of crops by photovoltaic modules, a gap is present in the formal research in the overview of implementation obstacles and its scalability. Understanding these aspects of the agrivoltaic application is crucial for both technological improvements, as well as enabling the spread, awareness, and sustainable development of this novel technology.

Existing studies and research have mainly focused on the obstacle of shading of crops by solar panels resulting in lower yields, or their economic and political feasibility (Pascaris et al., 2023), overlooking the entirety of the problem at hand. That would be done through incorporating the main important hindrance aspects altogether. To bridge this gap in research, this study is introducing a novel and innovative approach by interviewing field experts, developers and environmentalists, targeting all the main categories of aspects affecting the scalability of agrivoltaics. Furthermore, the use of artificial intelligence tools within the methodology of this study sets it apart, due to its novelty.

The application of this methodology to interview field-experts has yielded in the identification of the factors most affecting the spread of agrivoltaics. The results suggest that financing, the influence of the farmers' interest and legislation are by far the largest barriers.

7.1 Factors affecting the scalability of agrivoltaics

Financing received the largest amount of attention, with 68 mentions, as seen in Figure 20, thus has gaining the first place. This is an indication that the capital, due to the financially dependent nature of agrivoltaics, are the biggest issue. Therefore, investment companies or investors are wary of financing these novelty innovations, as their everlasting success is yet to be proved. Thus, the backers might be less opposed to investment in more proved methods, such as photovoltaic farms. However, an issue regarding the aspect of monocultural management of photovoltaics was raised within some of the interviews; finance supplementation or subsidies are topics to be very cautious of when implementing agrivoltaics. Poorly conceptualised projects can be planned more towards profit, utilizing more solar panels rather than focusing on the dual use concept. This could essentially doom agrivoltaics and proving the unsuccessful nature of such a project. In terms of how financing affects the scalability, it is again one of the main drivers. Simply put, if there are no monetary provisions, a project will not be able to be realised.

The farmers' interest, the next most frequently mentioned category is a very critical one as well. The farmers are the individuals that will pursue these technologies on their agricultural land. This will enable research and further innovation and is purely dependent on their awareness and enthusiasm for agrivoltaics, and the willingness to take risks. The implication of this result is the needed focus of governmental bodies on the cooperation with farmers, sustainable development promotion and further the interlocked financial support.

The category of legislation was expected to achieve a higher ranking. Given that the technology is facilitated through the presence of legislative measures, it is of necessity to consider this a major aspect. In light of the Czech legislation that is currently (as of March 2024) waiting for the second reading in the Czech Parliament (personal communication, Krčmář, February 29, 2024), the proposal is extremely restrictive. This is harnessed through a considerably restricted framework (for further detail, see section 4.1.3). Given that approximately half the interviewees are Czech, it was expected that the topic of legislation would be more frequent.

An element of surprise was the position of landscape planning (spatial planning), as shown in Figure 20. A major obstacle within some directives is still present; whether agrivoltaics should obtain a specific zoning plan, or whether it should remain as agricultural land. This remains a significant question among the proposals within the Czech Republic (personal communication, Bím, February 29, 2024). Each country has a different approach, though some countries are faced with a harder challenge. In contrast, for example, in France, the majority of agricultural land is not privatized (personal communication, Bím, February 29, 2024).

Even though these factors occupy the top three positions on the rankings chart, it is crucial to understand that neither is less important than the former. To enable the implementation of agrivoltaics, these three areas are the most critical to focus on. Providing largest amounts of support and, (if applicable) low-restriction frameworks, could be revolutionary for the field.

Additionally, the findings of this study challenge the conventional understanding of agrivoltaic scalability. A majority of the interviewees have favoured the idea of a small-scale rather than a large-scale application. This opinion was shared by the researchers, as well as environmentalists, though mostly an untouched subject by the larger company personnel.

"*I believe in local - a locally focused use of renewables where it makes sense where you have resources, where you have a possibility to utilize it and I'm not really good advocate for large scale solutions, like trading the energy internationally so I'm more* *for local use and so I see very good potential for local use of agrivoltaics in combination with other renewable resources*." (personal communication, Weger, December, 2023). For further information, check the transcript of the interview in appendix 10.2.

This suggests that a wider development and spread of agrivoltaics could likely lead to disagreements between researchers and corporate developers. The argument is that once the system reaches a certain size, it may become unsustainable, a concern associated with monocultural photovoltaics. Despite this, it is important to mention that most of the interviewees have agreed that agrivoltaics are a better alternative to monocultural photovoltaics.

"*Solar panels are making things more valuable our producing goods even ecosystem service goods, due to the dual use of land."* (personal communication, French, 2024)

"A benefit or agrivoltaics is the generation of a higher income from both crops and electricity, while in monoculture photovoltaics, the land is used exclusively energy production. A second benefit would be their income diversification for Farmers." (personal communication, Melcher, January 2024). For further information, reference to the transcript of the interview in appendix 10.3 is advised.

7.2 In greater context

Even if a direct comparison to other scientific studies is challenging due to the unique nature of the methodology, the results resonate that with the aspects of other studies, such as one by Pascaris et al. (2023). The results contain areas of overlap with this study in terms of techno-economic, stakeholder and political issues. Even though the concepts within the study are applied on an industry-based, developer level, the interviews within do not necessarily differ significantly to that of the interviews in this research. Piscaris et al. describes the communication among large-, mid- and small-scale developers, which outline the financial aspect to be extremely important. In other terms, if no funding or support is provided, the technology will not be able to prosper and be popularized within solar associations.

While it is a challenge to compare the results of this study to others, much like within this one, the findings of a study "A First Investigation of Agriculture Sector Perspectives on the Opportunities and Barriers for Agrivoltaics" (Pascaris et al., 2020) have also touched on the obstacle of landscape planning. Pascaris et al. have indicated that the problems with land-use that could eventually hinder the productivity of the landscape could lead to the lack of interest for farmers. Nonetheless, with the correct precautions, cooperation with relevant stakeholders and proper long-term planning for the landscape is crucial for further development of agrivoltaics. This study reveals a similarity and underscores the necessity for adequate landscape planning to avoid a large-scale development of agrivoltaics, which could lead to a monocultural land use. Though, again, the discussion on the size the project remains, as exemplified in the following quote:

"*In terms of landscape character, you always have to consider the scale of the landscape the base scale of the landscape and the Czech landscape has very small basic scale traditionally small houses. Small village is small and give small scale landscape structure. So that would imply. You need to be more careful about very large photovoltaics and I'm talking about photovoltaics larger than let's say quarter of hectare. Whereas when you have other landscapes that have a big scale. I think I used to live and work in Utah, which is a semi desert flat. Very large-scale landscape. I can imagine probably in Utah the acceptable scales would be larger than here. but not in terms of many hectares in terms of maybe a hectare again.*" (personal communication, Janečková, January 2024). For further information, a reference to the transcript of the interview in appendix 10.4 is advised.

While previous studies have also proved that the uncertainty within the market might be a significant barrier for developers (Pascaris et al., 2020 & 2023), this thesis' findings reveal differently. This factor was exclusively discussed in terms of stakeholder uncertainty and the concept of "not in my backyard" syndrome. Rather, a larger consideration was the level of education and expertise needed to pursue an agrivoltaic project. When considering photovoltaics, the projects are easily accessible to non-professionals, while agrivoltaic projects require a different approach. This may be attributed to the fact that agrivoltaics, if not carefully planned, can be hard to maintain.

The results of this thesis research, while derived from a unique set of methodological steps, underscore the utter need for financial support and farmers' interest. In alignment with both studies conducted by Pascaris et al. (2020, 2023), this perspective also acknowledges challenges not fully addressed in those studies. Vital among the obstacles is interconnection, a factor of considerable importance, particularly in the USA. This highlights the complexity of the topic of agrivoltaics, seeing as there are numerous factors that can have an impact on the success of its implementation.

Despite the uniqueness of the methodology within this study, the findings contribute to the ongoing debate within the field, which is still being shaped by government officials and legislators; legislative frameworks are still being designed and developed. It is crucial for legislative networks to create less restrictive frameworks for these technologies to prosper. The proper description of what agrivoltaics are a crucial step; for example, in some countries, utilizing animals for grazing underneath solar panels can be considered as an agrivoltaic, while not in others. However, clear outlines should be created, either by the European Union or independently by member countries. For the realistic emergence of agrivoltaics onto the market, effectivity and productivity within different climates and regions must be assessed. This will enable further research, optimisation, and adaptability to individual climates.

The study can provide an overview of the most critical areas that should be targeted primarily in order to promote and support farmers in applying this innovation. Spreading awareness on barriers and the possibilities when attempting to implement supporting frameworks, is crucial.

7.3 Scale of the project

It is also important to highlight the scale of the projects themselves. As was mentioned above, an agrivoltaic being constructed on a large scale can have an impact on the microclimate. Again, it would not be a sustainable solution to land-use patterns and problems. However, it is worth noting and answering the question of scale, is that agrivoltaics are still a better alternative to monoculture photovoltaics due to their dual-use aspect. The realistic application in the landscape and referring to the spatial plan within these projects, remains a challenge. Some areas are still struggling with the definition of agrivoltaics and propose the construction of agriPV solely on assigned agricultural land. Consequently, these obstacles might emerge during the planning stages of such projects in some countries. Thus, it is critical that this is also an area greatly focused on. However, from the personal communication with Ing. Petr Jílek (February 29, 2024), changing the legislation on the level of zoning and landscape planning can take from 3-6 months to be approved and applied within the legislature.

The possibility of redesigning a monocultural photovoltaic farm is an intriguing concept. Though these projects would have to be closely monitored for keeping a non-monocultural approach to the farming aspect.

7.4 Reflection and evaluation

The administration of interviews with field-experts, developers and environmentalists was pivotal in finding an overview of the necessary factors that affect the spread of agrivoltaics the most. Nonetheless, none of the factors can be considered as trivial; this research merely provides the overview and possible framework on the factors that need to be focused on the most.

A particularly challenging part of the methodological process was the gathering of interviewees, as many companies or individuals showed no interest in the prospect of undergoing an interview about this topic. Hence, it is important to gather a larger network of people that have mutual contact, thus showing more interest. It is beneficial to know the people in person, though that can deem to be difficult in some scenarios.

While this novel approach and method for assessing the obstacle factors employed within this thesis offers a fresh perspective on the implementation of agrivoltaics, its limitations can be seen with the lower number of interviewees. This may inhibit the applicability of the results within more formal settings, such as within political discussions, governance administrators or formal legislation documents. To be able to address the individuals within the scenario, a larger sample size of interviewees: field-experts, environmentalists and developers is needed. To tackle the problem of low amounts of interviewees, it is possible to supplement with an online survey. Although, the use of an online or electronic survey within this specific scenario with agrivoltaics for non-expert individuals would not prove useful. The general public and individuals without specialized knowledge often lack the awareness of this innovative technology altogether, posing a problem. In turn, this could potentially result in imprecise results. Therefore, controlling the identity and background of the respondents and or interviewees is of interest within this research to keep it professional, educational, and expert-based for best results is of interest.

7.5 Future research and implications

The implications of this thesis research and its results extend beyond the academic setting, by offering awareness on this new emerging technology with many applications in different regions, climates, and conditions. A blueprint is provided to consider the scale of agrivoltaic projects for developers and development companies or individuals pursuing this technological sustainable advancement. Furthermore, the thesis can act as a strategic guide on focusing on the more pivotal areas and factors that should be focused on, especially within the legislation formation stage.

This thesis offers the opportunity for further and future investigations or research, including the focus on how the scale and size of an agrivoltaic project might affect the wildlife and biodiversity within the study area. What's more, the future research within the field itself offers extraordinary opportunities, from microclimate studies on different scales, to studying the environmental possibilities and possible innovations.

8 Conclusion

This thesis aimed to investigate the scalability of agrivoltaics as an alternative to conservative monocultural photovoltaics. Agrivoltaics are a dual-use sustainable development strategy, utilizing land underneath solar panels for agricultural purposes. It is a very innovative solution to current issues of a monoculturally managed landscape, whether that is an agricultural field or corporate development of photovoltaic farms. The aim was to fill the gap in research, within identifying the possibilities and restraints of implementing agrivoltaics into existing agricultural or photovoltaic systems. The objective of the methodology was obtaining the opinions and views of field-leading experts from different backgrounds and nationalities. It is critical to consider its various aspects to gain a balanced perspective and comprehensive understanding of the issue.

The investigation revealed that the primary area of concern is financing, as agrivoltaic projects are economically more demanding than conventional photovoltaic farms. Further, the farmers' interest is also a key component when considering this technology - these individuals are the ones that will be implementing this technology and realising it on their agricultural land. Lastly, according to the results, legislation is the 3rd factor that will have the most effect on the nature and possibilities of the projects. However, all the factors considered are extremely important within agrivoltaic implementation and are required to make a successful project.

Practically, this study has significant implications and an impact on the area of sustainable agrivoltaic development. With that in mind, it is aimed at all bodies engaged in projects, including those in search of direction and guidelines, educational objectives, as well as incentive for further research. While the findings are definitive, it is important to highlight the limitations of the research, such as a lower number of interviewees. It is crucial to emphasise, however, that all of them are either field-leading experts or recognised, environmentally driven individuals.

Ultimately, this thesis not only advances the understanding of a wide spread of agrivoltaics, but also opens new possibilities in investigating other aspects of the technology. Further research could explore the impacts of different agrivoltaic structures on the microclimatic conditions and wildlife. Understanding that small-scale projects are a more sustainable approach is key to avoiding monocultural practices. Separately, the principle of applying sustainable methods across all domains, whether agricultural or photovoltaic, underscores the remarkable potential of agrivoltaics.

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Figure 20: Graph created by author

Figure 21: Graph created by author

Figure 22: Graph created by author

10 Appendix

10.1 Prompt used within ChatGPT to count keywords

Count the occurrences of exact matching keywords from specified categories in an interview transcript, focusing exclusively on the interviewee's responses and excluding the interviewer (Eliška Pechlátová).

It is extremely important to exclude related words or variations that do not precisely match the specified keywords. An exact match is defined by for example within the farmers category, only these words will be counted: farmer, farmers, landowner, landowners, owner, owners, maintenance, cooperation. Create a table with two columns: one for the name of the keyword category and the second for the total count of exact matches of keywords used.

These are the exact words to be counted for each category:
Legislation – legislation, legislative, regulations, regulatory, frameworks, framework, permission, permissions, permit, permitting, policy, policies, rule, rules, law, laws, legislator, approval, approve.
Farmer – farmer, farmers, landowner, landowners, owner, owners, maintenance, cooperation.
Technology – technology, technological, innovation, innovative, automatization, robotisation.
Knowledge – knowledge, knowledgeable, education, educated, research, experienced, experts.
Politics – politics, political.
Planning¬ – planning, landscape, land use, farmland
Stakeholders – community, stakeholders, locals, communities, public, acceptance, "nimb" (not in my backyard), "nimbing".
Economy – economy, economical, economic return.
Finances – investment, investors, financial, financially, finances, finance, money, monetary, profit, profitability, profitable, financing, expensive, insurance, insurer, insurers.
Climate - climate, physical, weather, hot, sun, extreme weather, sunny
Interconnection – grid, interconnection, utility

If you understand, please respond with ">" and I will provide the transcript.

10.2 Interview transcript with Ing. Jan Weger Ph.D.

Eliška Pechlátová (00:00): All right. Hello, so we are at the interview doctor Jan Weger. So do you think you could introduce yourself a bit?
Jan Weger (00:10): I am researcher Dr. Of environmental sciences and I worked for 30 years at the Research Institute for landscape and ornamental gardening, which is research organisation of Ministry of environment, and I focused most of my life on Research on energy crops energy biomass and also renewable resources.
Eliška Pechlátová (00:42): Mm-hmm. Okay. And do you think just you could tell me quickly? What is your background in agrivoltaics photovoltaics and what your current work in that field is??

Jan Weger (01:07): Okay our department, which is called Department of photo energy bioenergy was established in 90s and from the beginning. We were focusing also on other renewable resources than biomass so photovoltaics. Nineties was part of our research. But then we due to different changes. We focus mostly on biomass as our main renewable resource of Czech Republic, maybe five to ten years. to ten years. We also started to look again at other renewable resources, and we visited some as you mentioned some of the agrivoltaic Farms. I think the first one the large one which we visited was in Germany. I'm not sure don't remember the name now, but I know that it was on the place of former kind of concentration camp, which was not very famous history for the landscape use, and they use it for photovoltaic farm. In the Czech Republic but was more observation and in last five years. We started to look more on possibility to use photovoltaics also at our Institute and two years. We met with people from UC the centre for modern building of check Technical University in Prague, and we started to look what would be the novelty of research in agrivoltaics. We are as you understand before we are mostly field researchers with crops on field and they are photovoltaic experts and we found an interesting overlap, which is called agrivoltaics. And within the agrivoltaics, which is kind of clever use of photovoltaics on agriculture culture soil we found possibility to combine it in research. Agroforestry with Agrivoltaic. So, it's one of the first experiments maybe even in Europe where you combine trees. On agriculture soil, which is agroforestry with agrivoltaics. The solar panels are between the trees and What are the problems with it? So that was our way to start real work on agrivoltaics. And I must say it's small dimensional and it's experimental. But it's not easy way and I think it's good that the research is doing it before actually somebody tries it in in practice.
Eliška Pechlátová (04:37): Okay. Oh, thank you. And also, when you were starting to do the agrivoltaics where you were doing the agro-forestry with the photovoltaics where you hesitant or if yes, if not, why?
Jan Weger (04:55): I think opposite as researchers. We are curious. We are interested in doing Innovations. So, it's our work we must do it. Otherwise, we will not get financing for our research. So, we really must look for new ideas and new combinations. So, we are not hesitant. It was real like interesting excitement to find colleagues who are experts in photovoltaics and to find the overlapping with something new which very few people probably will try and going through, and I believe that also in among the farmers you can find similar people from the meetings, which we have Farm. It's not It's not the majority It's usually the Pioneers but you can also find People Like Us who are excited to do it. And I think they are important because they are the light bearers. So, I think it's not only us researchers, but you can find people like us also among the farmers.
Eliška Pechlátová (06:23): Thank you also. What do you think are the factors which affect the scalability of agrivoltaics Within? Locally regionally worldwide. What do you think? Whichever one you want to talk about varies across different regions and climates.
Jan Weger (06:46): hmm Okay, I think this is a question which my I may not be right expert to ask. I think what you mentioned in the end regions and climates. I think that there definitely might be regions maybe locations and especially climates where photovoltaics are much more efficient. And could be used and I'm not sure as I'm a repeating myself, I'm not an expert that the Czech Republic is the is the region where we have real excellent conditions for development of agrivoltaics. I believe in local - a locally focused use of renewables where it makes sense where you have resources, where you have a possibility to utilize it and I'm not really good advocate for large scale solutions, like trading the energy internationally so I'm more for local use and so I see very good potential for local use of agrivoltaics in combination with other renewable resources. I'll give you an example, we had very nice experiment where we produce biomass through the winter. So, I think I believe more in local use than really scalability in Czech Republic in large scales, but I believe there is some potential but not like in comparison with let's say Sahara or some areas where the photovoltaic is really can produce a lot of energy and on a large scale.
Eliška Pechlátová (09:21): Okay, thank you and based on your research. Especially your programme is very specific. But did the crop yield increase decrease or didn't have a change

because of the ABS that you're using. I mean, I know of course it's affected by the trees that you have in between the rose. But what did you observe?
Jan Weger (09:46): Okay. Yeah, it's maybe one very specific result or experience or a result of this combination agroforestry agrivoltaics that we already have enough in the middle of tree lines of the trees. Which are affecting the crop annual Crop Production the info what we learn. It's just a result of two years experiment and it's not published is that trees influence the conditions production conditions of crops much more than the panels, which are between the trees. The panels are adding little bit to that affect the shade temperature in very close distance to both these, but we didn't find influence bigger or statistically evident of the panels on yields of crops. Yeah. I didn't say and I say that of course trees with help of other ways decrease the yield of the crops, but it's also question of the agronomy. Think the idea is to not grow not waste the soil which is very close to trees and photovoltaics for a crop production because it's a probably better to leave this land to other use maybe just a grassland then production of crops, but it's maybe a little more specific question Yeah. So yeah, it's influencing but photovoltaics don't play the key role in this influence its trees which are changing the conditions much more.
Eliška Pechlátová (11:57): Mm-hmm. All right, and what would you say that the invite economic and environmental benefits of agrivoltaics compared to monoculture photovoltaics. We were talking about how you don't support the large scale, you know Renewables sometimes so what do you think about like the benefits of the agrivoltaics compared to that?
Jan Weger (15:26): I am the advocate for local use not very large. I'm not against the large but I think I see the better effects on local scale. And in that case if you are looking on local scale you have to you should have at least two possibilities how you will utilize the energy if it's you will use indirect tree for some kind of work which you can do if Will store it in your small battery, if you will sell it to the factory next to you or to have as a smooth small and medium side producer of energy have a good ideas and have possibility to switch from one to another. I think the one of the nice examples is implementation of these. I grow old tax into existing biogas plans or similar other combination with other energy resources and biomass as a solid fuel. It's interesting because it can be stored. So, I think that's advocate of this combination, of course as I mentioned.
Eliška Pechlátová (16:44): okay, and what do you think are the challenges that can be associated with building or adopting agrivoltaics.
Jan Weger (16:54): Okay, legislation. I think the legislation is the big thing then as because as I mentioned we have a agrivoltaics here, and actually we started before the legislation was settled or is kind of in process and we know that we wouldn't be allowed to build this plant official on Commercial level. Yeah, this this Combination which we produce as an innovation is won't be allowed in check conditions. So, I think that that's important. And I think also technological challenges because to get a good quality of Technology might be problem. We experience long time for delivering some of the some of the products which we needed. And then I would say also. And this is a lot of the latest experience that agrivoltaics has probably a slower return economic return than full scale agrivoltaics. Farmers actually mentioned that if the farmer thinks of using his field for producing electric energy, he's for him for him or her it's much more interesting in current conditions to sell it as a whole field for full scale agrivoltaics then modern agrivoltaics horizontal and vertical because it's much easier and his income is quickly much faster. So I think the economy will play a role to in in it.
Eliška Pechlátová (19:12): All right. Thank you and how would you say the agrivoltaics can be integrated actually into the current agricultural systems?
Jan Weger (19:27): Yeah, I think it can be but yeah, I think I mentioned a few times so I think it can be combined with like local energy and energy system of the farm or existing. A company energy strategy, but it requires quite a lot of knowledge. I think. It can take it as a positive So I think we have or we should have thing. quite a lot of educated young people who would be willing to go to the village and become local energy experts or some older ones which can teach them how to do local Energy Systems the communities and energy communities and so on. So, I think there's a potential, but it requires knowledge and good. Good planning. Which may be at the same time the barrier because as I mentioned the farmers

mentioned on our on our seminar that for farmers who is looking let's say for solving some solution quickly. It's much easier to solve whole field and leave it on Energy company which purchases the soil to make full scale full scale for scale photovoltaics on agricultural soil instead of doing this long-term planning and integrating these agrivoltaics into this system.
Eliška Pechlátová (21:51): Yeah, yeah, definitely. It's going to be interesting to see, and what do you think are the future prospects of agrivoltaics? And how can they be improved if they're not that good?
Jan Weger (22:03): I think I think I'm evolutionist. So, I believe that this experience which we will have in next months and years should give us idea how to how it should be better promoted. I personally kind of believe that in principle people are interested in positive development. So, I would give them more trust more give the legislation a little bit less stricter rules and give people or Farmers or landowners freedom to integrate their system into existing Energy System in so but I'm really not expert and I think the first step which we did here is was correct. What I see the prospect I see it's an Evolution which will need some corrections and we should evaluate the results of first year. Of our Global ties here and see speak with those who are interested the Pioneers among the farmers among owners and ask them what their main obstacles were and what they would like to improve on it. It's very often. They are there are some small not small but some barriers so in limitations which A production that the limit of the production perform connection limits to the electric grid. So there's a lot of technical questions and I think the evaluation of the first year is good and hopefully there will be also willingness to change the rules in few coming years to make it more accessible to Future Energy communities and maybe Farm communities.
Eliška Pechlátová (25:28): All right. Thank you and last two questions. What would you say? Let's go back to the scalability again. And what would you say are the most limiting factors that affect the scalability of agrivoltaics both on a national international local scale. So, we have some options: financing (investors), climate, interest, legislation, or something else and if you could explain.
Jan Weger (26:01): Well, I think I think you are missing here the economy. The Investors are looking for like economic return of their investment. And so, you probably know that the boom was allowed by the very first fortunate and advanced advancing condition economic conditions for building photovoltaics on agriculture soil, which was long term purchase price is from Electric grid. So, I think the combination of conditions, I would say climate and soil because you also pay for the soil and economic conditions would be probably the bay the main incentives for a large development. And of course, these could be Working only if the legislation will allow this kind of a company. So, I would say usually the development of new resource starts slowly with where you overcome the legislation problem, then you have period where money is connected, and then economic calculation start to play role. So, and maybe would like to correct my answer that first legislation which allows the development in a given area given a ring and then the economic incentives or economic conditions together with conditions like physical or climate conditions together and because we also in the Czech Republic we have quite different weather conditions and it might be that in let's say a deep valleys where you have a lot of a lot of fork and whether with clouds during the winter might not be so advancing in comparison with the mountains conditions. Yeah, so it's not I think it's the questions of expert does not focus in this area if it may finish like this.
Eliška Pechlátová (29:17): Yeah, unless question what are the situations or conditions where you feel that agrivoltaics would absolutely not be effective and why?
Jan Weger (29:29): Mm-hmm. Okay, I think from my experience with agrivoltaics is which would be built just because of subsidies that you just are interested in subsidies and not in utilization because these were examples in in many previous cases where the subsidies were very high, and people were building. biogas plans biomass plans agrivoltaics only because subsidies were so high and then when the conditions has changed these installations lost its efficiency. I think this would be this would be mistake. So, the high subsidies would be very risky way to promote agrivoltaics. I think it should be only. Time limited for the Pioneer installations and that would be that would be I think the riskiest way how to promote agrivoltaics thanks to give really high subsidies to it. I don't think that we will make this

mistake again. So, this is and then if you if we go over this this condition that's a high subsidies if we were normal subsidies or normal conditions. I think the mistake would be to build it without planning how you will utilize the energy from photovoltaics at least into to very ends, you know for yourself and providing it to the grid or to the community, I think. Maybe I would like to finish in a positive way. I think the agrivoltaic should be integrated as part of the energy communities the new law and new ideas which we have about actually a decentralization of the energy system in Czech Republic in an evolutionary way slowly step by step. So, I think that would if it would be built just very Island type of agrivoltaics or just focusing on selling it to the to the grid that would be mistake. It should be flexible.
Eliška Pechlátová (32:25): All right. Thank you.

10.3 Interview with DI Sophia Melcher

Eliška Pechlátová (00:14): Great. All right, so, can you just quickly introduce yourself a little bit?
Sophia (00:19): Of course, my name is Sophia Melcher and I'm a project developer in Austria at the RWA. And it provides five Innovative products and services. And one of these five products is energy. And the area so last Solutions is cooperated in the energy department. And yeah, we do. some kind of you know different PV businesses like rooftop PV and also Equity beam and I'm my focus is definitely on the development of every PV.
Eliška Pechlátová (01:24): Mm-hmm, great. All right, so I think that kind of covers the first question. So now on to the second one. When you were building the Agro will take where you hesitant in the initial stages and why?
Sophia (01:41): We already built a group PV. Plant in Austria. It is in Pöchlarn it is. All in all, it is a five-hectare PB plant with a smaller part of equipment with about one hectare. And in this part, we test three different Equity V Systems. The first one is overhead PV the second one the fixed its PV with South grounded South ground mounted PV. And the third one is the tracking PV. and I would say no, I'm not hesitant because everybody offers several advantages that combines agricultural activities with solar energy production, and yes, it means that you have better land use better efficiency We have economic diversifications for farmers. also Advantage is the Environmental benefits.
Eliška Pechlátová (02:58): How do the factors that affect the scalability or spread of agrivoltaics? varies across different regions and climates
Sophia (03:15): The scalability of agrivoltaics is influenced by environment environmental agricultural economic and social factors that vary across different region regions and climates. To look to local conditions and considering the specific transits challenges of each area is essential for success. For example what the availability in regions facing Waters scarcity, the integration of solar panels with agriculture may need to consider water saving techniques. or for example crop types and agricultural practices The type of crops grown and the agricultural practices employed very across regions. Certain crops May benefit from partial shading provided by solar panels While others may require more direct sunlight.
Eliška Pechlátová (04:21): Great, great.
Sophia (04:21): Yeah.
Eliška Pechlátová (04:23): Thank you. So that kind of ties into the next West question. And you can also say from your experience. Do you believe that crop yield is increased decreased or has no change because of the agrivoltaics.
Sophia (04:40): Yes, I already told you that we have an MVP. plant or every ppv ever in person where we test different models, and we did a study. The study was about how does the equipment system affect the winter wheat growth? And we combined to systems the fixed system and the tracking system and what we saw there. Is that the year in kilogram per hectare for system one for the fixed system. Had a yield increase by about 14% in the Shaded area and the other system the tract system the variations are smaller, and the yield loss is less pronounced but in the shaded areas we had some yield increase about 7 to 14% depending on the system.

Eliška Pechlátová (06:04): Mm-hmm, great. Uh, thank you and what would you say are the economic and environmental benefits of agrivoltaics compared to monoculture photovoltaics?
Sophia (06:16): Mm-hmm economic benefits is of course the efficient land use. So agrivoltaics allows you will land use for agriculture and solar energy. A benefit or agrivoltaics is the generation of a higher income from both crops and electricity, while in monoculture photovoltaics, the land is used exclusively energy production. A second benefit would be their income diversification for Farmers So agricultural types provide additional income sources through the sale of agricultural products and solar electricity allowing Farmers to diversify their income streams and improve financial stability. And on the other hand, the environmental benefits are in the increase of biodiversity. And with while monoculture photovoltaics may lead to habitat loss. also benefit could be the water conservation the shade it from s or into shade from solar panels in agrivoltaics systems reduces water evaporation potentially leading to water savings especially in dry regions and the third benefit is the temperature regulation. So shading effect of solar panels in agriculture systems. Can moderate extreme temperatures particularly beneficial in warmer regions.
Eliška Pechlátová (08:05): Great. Thank you. Um now what are the challenges associated with the adoption of agrivoltaics? And how can they be addressed, and you can even say what you did in your project?
Sophia (08:25): and Solutions in adopting agrivoltaics for example come betting land use so the challenges is the limited agricultural land creates competition between space for crops and solar panels. So the solution is to implement elevated solar installations or agriculture systems that allow sunlight to reach crops supportive policies and incentives can encourage dual land use promoting efficient space utilization Another challenge is the crop yield impacts. So solar panels May reduce sunlight exposure potentially affecting crop yields. the solution like in Pochlarn is to First of course to carefully choose crops that are less sensitive to shading like winter wheat or soya. And, ongoing research can provide inside into optimal crop-solar configurations. So, studies must be done, and I think it is very important. Another one. Another challenge could be the community acceptance. So local communities may be resistant to change in land use practices or perceive agrivoltaics as its disruption or traditional farming. so, it is important to engage with communities through education and awareness programme programmes. That can address concerns. also involving local stakeholders in the decision-making process. Yeah.
Eliška Pechlátová (10:34): Great. Thank you. And how would you say that agrivoltaics can be integrated into already existing agricultural systems. Is it possible?
Sophia (10:46): Yeah, that is possible. And I think the solution is overhead PV for berries and fruits. So we call it "fruitovoltaics" that yeah is maybe the best way to integrate it into existing agriculture systems because of the dual land use through elevated light transplant solar panels. That's you can say this is a substitution from of the plastic rain covers through the solar panels or also through hail net.
Eliška Pechlátová (11:30): Mm-hmm. All right. Thank you and What are the future prospects of agrivoltaics, and can they be improved?
Sophia (11:43): Mm-hmm, um agrivoltaics show promise for the future and their success can be improved through technological. Advancements ongoing research supportive policies and widespread adoption also clear Innovation collaboration and customized solutions for diverse agriculture context key to maximizing their potential.
Eliška Pechlátová (12:14): Great and last two questions. So, what would you say like your opinion? Oh are the most limiting factors currently affecting the scalability of agrivoltaics both on a national International and local scale. So, we have financing or investors climate interest legislation or something else and can you please explain?
Sophia (12:44): Um, yeah to financing to this point limited access to financing and investment can hinder the widespread adoption of Agri PV projects. So high upfront costs and perceived risk May. deter investors to the second one to climate regional variations in climate including extreme weather events, may impact the performance and officials of equipped systems. So unsuitable climates, may limit widespread adoption. to the interest lack of awareness and interests among Farmers stakeholders and communities may slow down equipped adoption.

Resistance change and family familiarity with the technology can be a barrier. two legislation existing legislation and Regulatory Frameworks may not be adapted to accommodate the unique characteristics of ABP Also unclear, or restrictive policies can impact implementation. And the last point is land use and space contain constraints. limited availability of suitable land for agrivoltaic installations coupled with competing land use can constrain scallop scalability. Yeah.

Eliška Pechlátová (14:36): Mm-hmm. Thank you and last questions. Are there any situations or conditions where you think that agrivoltaics would not be effective and why?

Sophia (14:49): Mm-hmm, as I already mentioned one point is the highly shade sensitive crops. crops that require abundant sunlight for optimal growth may not Prosper. Well under solar panels. And potentially leading to reduced years. also reaches with limited sunlight and areas with consistently low sunlight levels. The efficiency of solar panels may be insufficient to justify to a land use making equipped less effective. also, the lack of financial support without financial incentives or support the initial investment and maintenance costs. Associated with equipment equipped maybe prohibitive for Farmers limiting its effectiveness. Also the resistance from agricultural community So if the agriculture Community is resistance to them to the integration of solar panels due to Patchwork or traditional reasons everybody adoption May face challenges. And my last point is small land Holdings in areas with small land Holdings with space is limited. The implementation of everybody may not be practical or economic economically by able.

Eliška Pechlátová (16:37): Great. Thank you. And lastly. Would you like to add anything? Do you have any comments?

Sophia (16:46): um I would say our project in Portland. Yeah, it's great to see how crops. How they potential of different crops is in combination with our agrivoltaic systems. It is very important to have a strong. partners that do their studies like University or some other experts though I think it is very important to have those Partners on your side and in a very early age so from the beginning from planning from implementing so Yeah. I don't know how to say such to have a Partners on this side. Yeah.

Eliška Pechlátová (17:45): Yeah. Yeah, great. Thank you.

10.4 Interview with doc. Ing. Kristina Janečková Ph.D.

Eliška Pechlátová (00:20): All right. So, could you just quickly introduce yourself, please?

Kristina Janečková (00:26): Okay, so, my name is Kristina Janečková, I'm an associate professor at the department of landscape and urban planning and check university of Life Sciences and I'm teaching the course of landscape planning, landscape management, landscape history and working in practice on projects in the same areas working right now. We're working with organic farmers quite a lot to help them improve a landscape that they're working in because they're already organic, but they want to do more for our life and for landscape stability. So, we have a project it's funded by European Union.

Eliška Pechlátová (01:57): Okay. All right. Thank you for the introduction. And I just wanted to ask do you maybe have a background or some knowledge in agrivoltaics or photovoltaics? And or do you have any work in that field or have you visited an agrivoltaic Farm something along those lines?

Kristina Janečková (02:19): Okay, so we did quite a lot of work on wind farms windmills wind turbines not so much on agrivoltaics. But of course, I visited them and see them and consult them in part of my practice with for example landscape character. It's a typical case for landscape character assessment and they exist in many of the areas where we are working. So, we have to work with them. So, in that not research wise but practice wise. Yes.

Eliška Pechlátová (02:53): okay, okay and Just kind of like an opinion-based question. If you were maybe interested in pursuing building and agrivoltaic - Would you be hesitant? Why?

Kristina Janečková (03:09): Hmm, I would be quite happy to build them on roofs on roofs of especially of industrial buildings parking rooftops private house rooftops any build structure that already exists. I am totally for it. I think it's one of the best ways how to get renewable

energy. In terms of agrivoltaics, there are ways to make them more sustainable. I know that some farmers are for example able to grow vegetables under them. It's a matter of scale because up to certain scale. I would be willing to consider the idea. And of course, you have to consider manufactures in landscape. I would be going to consider if the scale gets too big then there is quite a lot of impact on microclimate, and it provides glares. So, I would think that it's really quite a lot a matter of scale. and always other types of photovoltaics such as rooftops should be considered before agricultural takes but given the need for renewable energy. I think agrivoltaics can be considered under certain circumstances. And I think overall they have a much more benign impact than the wind farms wind farms. I think in the conditions of the Czech Republic are quite harmful.
Eliška Pechlátová (04:53): Mm-hmm, right. Thank you. And what do you think how do the factors that affect the scalability of agrivoltaics? How do they differ across different regions and climates?
Kristina Janečková (05:11): In terms of landscape character, you always have to consider the scale of the landscape the base scale of the landscape and the Czech landscape has very small basic scale traditionally small houses. Small village is small and give small scale landscape structure. So that would imply. You need to be more careful about very large photovoltaics and I'm talking about photovoltaics larger than let's say quarter of hectare. Whereas when you have other Landscapes that have a big scale. I think I used to live and work in Utah, which is a semi desert flat. Very large-scale landscape. I can imagine probably in Utah the acceptable scales would be larger than here. but not in terms of many hectares in terms of maybe a hectare again.
Eliška Pechlátová (06:38): So, you're basically saying that it's based on the look and the surrounding landscape the look of the agrivoltaics will take should be let's say projected onto that.
Kristina Janečková (06:52): Yes from the visual point of view. You need to consider the scale of the landscape. Then there is the microclimate point of view.
Eliška Pechlátová (07:21): Okay, thank you. Thank you. I value your opinion. Um Do you think that the crop yield underneath or around an agrivoltaics could be increased decreased or has no change because of the agrivoltaics?
Kristina Janečková (08:15): Oh, yeah, if the photovoltaic is sufficiently small that it doesn't significantly influence microclimate. Then the yields should stay the same if the photovoltaic warms up the microclimate. It's dark right the it's then you're going to lose crop yields because lately water has been the limiting factor in agriculture.
Eliška Pechlátová (08:47): Thank you. What would you say are the economic and environmental benefits of agrivoltaics compared to normal monoculture photovoltaics?
Kristina Janečková (09:11): Some farmers are saying that for example for growing vegetables it may not be such a bad thing to grow them under photovoltaics because vegetables suffer from glare the sun burns them takes the water away. So, I think that in smart agriculture precise agriculture there can be benefits but I'm not a professional. I don't know the numbers is just from what some people that I work with told me that they're thinking about it and the exploring the idea and then it might not be so bad. But that's as much as I know about it.
Eliška Pechlátová (10:07): Okay.
Kristina Janečková (10:08): I would say that better agrivoltaics than just photovoltaics.
Eliška Pechlátová (10:14): Good. Thank you. What would you say are the challenges that are associated with the adoption and implementation of agrivoltaics and how can they be addressed?
Kristina Janečková (10:29): So Now I'll leave the scale issue which I think is big but we already discussed it. I think planning permissions now. I'm back to the context of the Czech Republic because that's where my own most of my experience comes from. But I think the blank permissions are going to be difficult because there is a lot of nimbism, you know that term nimbing not in my backyard like
Eliška Pechlátová (11:00): Yes, I do.
Kristina Janečková (11:00): people agree with photovoltaics in general, but don't put them in my backyard. So, there is a lot of that people just don't want that in their landscape. They don't

want to look at it every day. They are afraid of potential health benefits. Of course. It is a new technology. Nobody fully knows how it could impact People's Health. um, and there's just plain conservativism which I understand. So I think planning permissions are going to be an issue how to overcome them in theory or in practice in practice your overcome it by money. You just give the people part of the part of the benefits part of the proceeds you give maybe directly to the people but maybe more likely to the Village you give the money to pay their road to do some plantings to you know improve and then they might weigh in the benefits and the sales, and they may decide for the for the football takes. So that's the level of the public and then there's the level of the of the Native protection agencies who will have something to say, but then you know that that we are planning the acceleration zones, right every region has to set zones where portable takes and wind firms, which is different thing are going to put we put without much of a permission process. The stakeholders will have only 15 days to put together any. any arguments against once they put the ones, they submit their arguments. They cannot add anything. So it's quite forceful this regulation and I think there's going to be backlash from people strong one. But that's the plan right now. so in in fact that would over overcome any challenges with introducing any form of sustainable energy development, but and what it was price. They don't even eia. The environmental is impact assessment will not be will not be required in these zones.

Eliška Pechlátová (14:42): Sorry, so next question. Um, how would you say agrivoltaics can be integrated into existing agricultural systems?

Kristina Janečková (14:56): Well, they would be considered. part of let's say the crop rotation. You would have whatever you're growing under the under the panels as part of your Of your agricultural system. I'm imagining that these crops that are this produce that can exist. Under photovoltaic panels would be consuming quite a lot of water because usually you get it would be vegetables. It wouldn't be let's say wheat, so you might need to budget that into your water system. But that's pretty much the only challenge I see there. Otherwise, it's just another field.

Eliška Pechlátová (15:56): Okay. Okay. And what do you think are the future prospects of agrivoltaics and can they be can they be improved?

Kristina Janečková (16:11): I am afraid that it's partly a political issue. that there are lobbies and if we did things purely on the basis of what's good for nature, then you would go for photovoltaics on roofs first then for agrivoltaics then probably photovoltaics then for wind farms. In my opinion, that would be the correct order. In which we should go but whether we do go in that order. I'm afraid will be very dependent on politics. and I'm not qualified to predict that

Eliška Pechlátová (17:00): Good. Okay. All right. Thank you and last two questions. What would you say are the most limiting factors affecting the scalability of agrivoltaics both on a national and international scale. So we have financing or investors climate. Interest legislation or something else and can you please explain?

Kristina Janečková (17:55): okay, so I'm imagining that the factors that include money will push for larger scale the environmental factors Will push for smaller scale? And it and legislation. Can go either way. What I'm a little bit afraid of and this is again, it comes from my work with the winter beans. is that the push for limiting CO_2 will be seen as the only environmental concern. That would mean that the legislation would push for upscaling. Which is not necessarily good for the environment. I'm afraid that there will be like a one-way limit CO_2 and let's not see any other environmental concerns. So Sure financing will be pushing it out. Sure, sustainable landscape planning will be pushing it down. But what way goes the legislation and actually the environment the big skill Environmental Group because sustainable landscape planning and environmental activism can be two different things. So which way do the environmental activism and the legislation go? It's really depends quite a lot on. Will they listen to our argument as landscape people? I'm quite concerned frankly about that. I'm a little bit afraid that it will go the way that's not the best for the environment and we have to work on that. I'm trying I'm in a number of focus groups with win first not so much with but the photovoltaics are not concerning me as much as photovoltaics. So, we're trying to tell people Well, they listen. That's a question.

Eliška Pechlátová (20:09): right and thank you and last question. What would you say are the situations or conditions where you think that agrivoltaics would not be effective and why?
Kristina Janečková (20:29): I think if you have areas where the crops that you can grow in agrivoltaics. Already are not in Optimum. For example, you have an area that is not quite lowland a little bit more up already. You can grow vegetables, but already it's not an optimal place. I can imagine that in such cases. It will not work with photovoltaics. The crops the yields would be too little to be a good return to be viable. So I would see that limit. And then of course, I would see a limit in environmentally valuable areas. I think there it might do more harm than good.