The possibilities of drone inspection technology in the renewable energy industry

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ABSTRACT
With drones being a technology with a lot of potential in a variety of sectors such as the renewable energy industry, research has to be done to see what the benefits are with drone technology, plus what the maturity of the application and what the potential limitations are. This research answers these questions and provides insights and recommendations to further this respective field by applying a scan tool which maps out the readiness of different dimensions. These results then get translated into specific interview questions. This concluded that drone inspection in the renewable energy sector is the next and better step for inspections and that mostly regulation and social problems need to be dealt with by providing more easily accessible information, clear written rules and regulation without ambiguity.

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1. INTRODUCTION

1.1 Situation and complication

Drone technology is an emerging market with a wide variety of possible applications ranging from package delivery to surveillance. Drone technology has been around since the first world war, but the most significant adoptions have been made in the last decade. However, many areas of professional Drone application are not matured yet in terms of market acceptance and wider application. [i] The commercialisation of drones is in an emerging state wherein "the market for commercial and civilian drones will grow at a compound annual growth rate (CAGR) of 19% between 2015 and 2020, compared with 5% growth on the military side", according to BI Intelligence [ii]. This branch of the drone industry is still emerging but has seen some rise in investment in the last five years in the commercial sector [iii]. To not let all these possibilities untouched, entrepreneurs and business need to step in to create markets for the potentially interested client base and align their interest in such a manner that it is also supported by policy makers. Furthermore, they have to deal with the modern business obstacles such as corporate social responsibility, ethics policy and change management which come with a market which just started taking its first significant steps and has a variety of different application fields. Henceforth, a promising application field that I would like to delve into is the inspection of renewable energy using drone technology. The sector is one which speaks to the imagination and is in line with the current state of demand in the Corporate Social Responsible (CSR) business environment and the growing need for functional green renewable energy sources to help make the transition from fossil fuels.

1.2 Research objective

1.2.1 Intro

The goal of this research is to figure out the maturity of the market and the current and future developments of the application field of inspection of renewable energy sources. Firstly, I will investigate windmills and secondly solar panels. The geographical focus for this research lies on the Netherlands. The secondary goal of this research is finding out the implications, challenges and benefits that come with the development of the market of drones across various dimensions of technology development. This research is part of a bigger European Regional Development Fund (EFRD/EFRO) project between the University of Twente, Saxion and foundation Space 53 to help further developing and expanding the cluster of business in unmanned systems (i.e. Drones) and to improve and work on a tool. This tool will also be used in this research to get a better understanding of the current state of the multiple Drone application fields. Besides, there are other similar setup researches being done by students about security, Agriculture and medical uses of drones.

1.2.2 Research question

For this research, I constructed the following research question: "What is the state and possibilities of drone technology in the renewable energy inspection market and what are the implications that come with the further development field?". The following sub-questions have been constructed to help answer this.

- What is the maturity state of this field across multiple dimensions of technology acceptance?
- How can these dimensions be developed in practice, and what are its most important challenges?
- What are the benefits of the inspection of drones in the renewable energy sector?
- How can we further develop the Space 53 tool?
- What is holding back the inspection of drones in the renewable energy sector?

1.2.3 Networking and building of the market

Adding to this all, another sub purpose of this particular thesis would be the enhancing and furthering of the drone industry technology and knowledge about the state of drones and the future that it might have. It might also connect people in a particular industry and have an insightful impact on businesses currently dealing with this emerging and upcoming market and help further EFRO and Space 53 in their endeavours.

1.2.4 Providing solutions

By identifying the weaknesses, I can again search for answers in similar business problems and learn from the specialised interviews the way the businesses are dealing with the challenges. This could help the rest of the market to deal with the problems they have, to after that further the cause to establish a place for drones in this world.

2. THEORETICAL FRAMEWORK AND THE CURRENT STATE OF RESEARCH

2.1 The current state of research

Following numbers by the neighbouring country Belgium civil aviation authority (BCAA) "the commercial use of drones is approaching the plateau of productivity" '[iv] in the Gartner Hype Cycle, as illustrated in figure 1. This means that the mainstream will start to adopt it. However, currently, it is still somewhere in the trough of disillusionment and approaching the slope of enlightenment. Therefore, providers have to improve their products to firstly satisfy the early adaptors to deal with the current loss of popularity to be thereafter found to apply to a lot of applications.

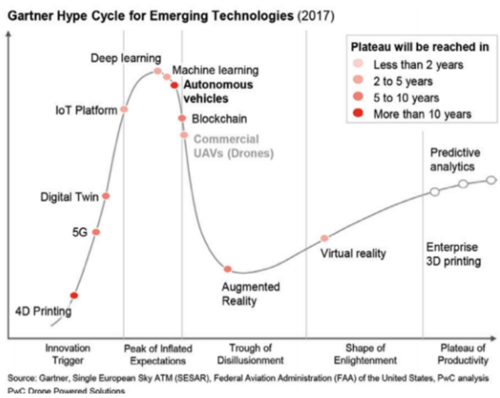

Figure 1 Gartner Hype Cycle

2.1.1 The current state of the drone inspection of renewable energy sources

The current state of drone inspection of renewable energy sources is an emerging one as experts say: "drone-powered inspections are in their infancy". The same experts from intel point out to the needs for standards and state that these drone systems can capture defects better than the human eye[v]. With PricewaterhouseCoopers analysing it as followed: Firstly, Drones need to comply with airspace organisations and need to ensure overall safety. Secondly, dealing with the massive amount of data that drones gather and the cyber privacy risks that come with this field. Thirdly, the aircraft users need to have potential insurance coverage available. However, the returns on new data and safety benefits do outweigh the costs and challenges by a milestone, with the data gathering even helping to figure out what other inspection needs would be in the future.[vi]

2.1.1.1 Research on Practical benefits of drones in Wind energy

So, what would be the current positive possibilities of employing UAVs to inspect wind turbines and wind farms? These would include: The frequency of inspection, speed and efficiency of defect detection can be considerably increased. Next to that, the need for equipping the wind turbines with expensive sensors can be eliminated, and most importantly, the risk of human injuries and downtime can be significantly reduced[vii] with inspections being able to take place 24/7.

Critical

These advantages might seem great and all. However, to achieve these advantages, we still need to make it fit within the business. This is where my research comes in.

2.1.1.2 Practical Solar energy

On the other hand, the current possibilities of the technology are as followed, as the main advantages of employing UAVs to inspect solar energy sources:

The advantages of integrating drones for PV farm inspection include: "inspection time reduced significantly (up to 90% reduction in on-site time of inspectors) and solar Cell level inspection of anomalies and autonomous localisation, identification, classification and prioritisation based on severity." [Vi]

Furthermore, drones assure a "direct reduction in safety risk of inspectors by eliminating the need to access unsafe locations and unnecessary exposure to electric shocks and Scalable offered by drones teams to inspect a large solar farm within a short time as compared to a single drone".[Vi] Moreover, the research concludes that drones "most importantly increased overall operational excellence achieved through workflow optimisation, reduced labour costs, increased productivity and enhanced safety." [VI]

Critical.

As expected, the same adaptation point can be made for the solar energy sector. Social and ethical problems need to be dealt with.

2.1.1.3 Challenges that come with drone inspection with renewable energy sources

Drones in green energy-related fields would be dealing with the following challenges:

- Steady flight and hover under unfavourable environmental and internal fault conditions
- The need for Weatherproofing the vehicle and its payload
- The Rigorous safety assessment and defining safety confidence level metrics
- Controlled and reliable flight under non-ideal conditions
- Enhancing battery life or the use of renewable energy sources for fuelling [Vi]

Furthermore, the regulations need to be in place, such as drones not being allowed to fly Beyond Visual Line of Sight (BVLOS).

2.1.2 Previous research

Different dimensions influence the maturity of drone technology. A system that can be applied to estimate the technology maturity and is already being utilised at NASA and the US Department of defence[viii] is the technology readiness level (TRL) system. However, due to the more intrusive and multifaceted nature of drone technology, more dimensions need to be accounted for and aligned. Therefore, we can learn from earlier literature about the gauging of the readiness of drone projects such as this particular research which is about the drone readiness of different countries. In the research, the index is divided into so-called components or dimensions, which in turn are divided into sub-indices which are assigned values based on data from sub-index scores, as shown in Figure 2. [ix]

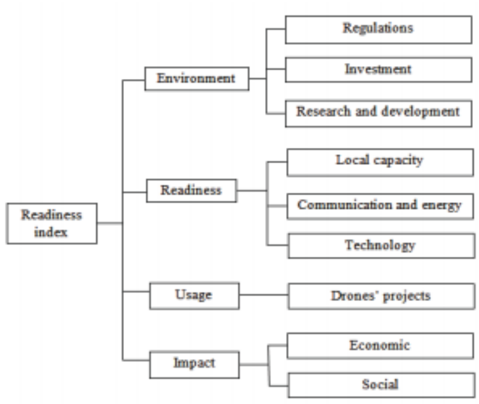

Figure 2 Drone readiness index 2017 ITU Kaleidoscope

2.1.2.1 Critical limitations.

The problem with previous research,[x] is the broadness of it. It used mostly secondary data, and the results of it are very dependent on the data collection. Besides, they also mentioned in the discussion that data gaps are a problem. However, as they also mentioned that this will be worked on in further research, and I do believe such readiness measures is a good start for my framework.

2.1.3 The technological transition of drones

With drones being such a new enterprise, it is currently still moving from the exploration for future business and application into the mobilisation of design and application. This will further help us understand the current state of drone technology. To make sure drone technology gets accepted sense-making needs to be in place supported by exposure to match the ambiguous and uncertain character of emerging business. This transition calls for constructive agenda writing to get the potential business of drones on the right track and get parties working together to change and push the agenda.[x] Furthermore, to get accepted, drones need to move trough technological transitions as shown in Figure 3.

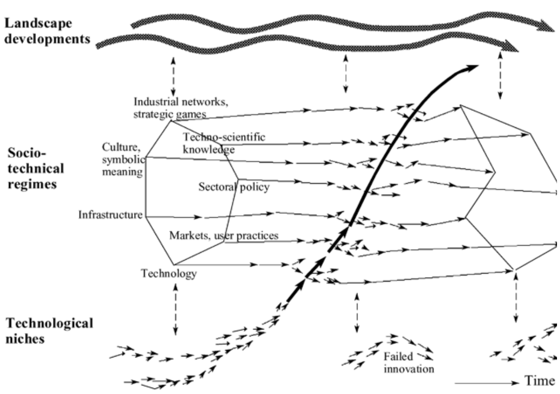

Figure 3 Technological transition

By moving from the original technological niche innovation, which is drone technology, to a new form of inspection, drones will have gone trough user practices, policy makings and research has been done. The drone will have to mitigate a lot of other different influences, such as policy, social technology and ethics to be accepted and further worked out. [xi]

2.1.4 Acceptation of drones.

Previous research shows that there is a positive effect on transparency and information on the drones application and the trusts in organisations. The initiatives such as Go Drone would play a factor in this. "Additionally, higher levels of trust towards the organisation heightened the level of drone acceptance and lowered the level of perceived control." [xii] Futhermore, to achieve acceptation of drones, the public needs to get informed on response strategies which mitigate risk through mass media and educational institutions. This might help improving the reputation of drones from killer machines or privacy interrupters towards a technology that helps our society. [xiii] This would already be possible by the Dutch government linking to services such as Go Drone.

2.2 Critical conclusion

The current situation of the use of drones for inspections is a hopeful one and overall an innovation which not only is cheaper but also the far more reliable, safer and profound option to gather information. With companies getting way more data which in these days is the new gold and energy companies potentially realising 95% ROI on drones inspection[xiv]. Henceforth, for the latter part of this research, I will focus on what is holding back the adaption of the drone technology but also what the challenges are. As to regulate and adequately roll-out inspection using drones, the problems in the other dimensions need to be figured out, and the lower scores need to be identified. Due to the technical research and possible applications of the technology already being quite advanced, there is still a lack of the current state of the fields business, ethical legal and social. Therefore, the research will mostly have to focus on Business and ELS perspectives since the difficulties of the implementation is that adoption is multifaceted. This will help further the field of drones by assuring that the public and the stakeholders which need to be trained, informed and regulated in the use of these machines will be able to deal with and or accept the negatives that come with drone technology and are holding back drone technology. However, "Het wetenschappelijk onderzoek en documentatiecentrum van Ministerie van Veiligheid en Justitie" of the Netherlands[xv] has been researching the use and policy of drones. However, the inspection of renewable energy is just noted as a possibility and is not explicitly delved into yet. There are, however, guidelines about the 150-meter distance between drones for professional use and the citizens, which is quite essential to the business.

2.3 Explain dimensions

In the following part, I will give an insight into the different dimensions and provide some theoretical background behind them.

2.3.1 Technical

As I will be geographically focusing on the Netherlands, I will focus on the understanding of TRL by following the definition from the European Space Agency (ESA), namely "In order to enable discipline-independent assessments of the maturity of a particular technology and the consistent comparison of maturity between different types of technology, all in the context of a specific system, application and operational environment." [xvi] Henceforth, I would like to apply a similar approach in the framework model and find similar models in the other respective dimensions. In the tool, I will use a scale similar to the scale shown in Figure 4. This scale will show the level of readiness of the technical aspect, with a focus on the level from just the idea and observations to the already practical application.

Scale	Description for each subsystem
1	Basic principles observed and reported
2	Technology concept and/or application formulated
3	Analytical and experimental critical function and/or characteristic proof-of-concept
4	Component and/or breadboard functional verification in laboratory environment.
5	Component and/or breadboard critical function verification in a relevant environment
6	Model demonstrating the critical functions of the element in a relevant environment
7	System prototype demonstration in an operational environment
8	Actual system completed and qualified through test and demonstration
9	Actual system proven through successful mission operations.

Scale according to ECSS. (2017). *Technology readiness level (TRL) guidelines.* Noordwijk: Europ

Figure 4 Technical readiness levels

2.3.2 Ethical

For the ethical dimensions, previous research has shown that to get a real overview of the ethical implications. You need to look at it from a multitude of levels that is shown in Figure 5. [xvii] The paper also gives an example of an ethical checklist which allows identifying issues and shortcomings which otherwise might have been missed. However, this approach might always be incomplete and only may result in ethical issues for a particular field of technology, and specialised issues might be missed. The specialised nature of the Space 53 tool helps combat this, as the tool is specifically designed for the analysis of maturity of drones' ventures.

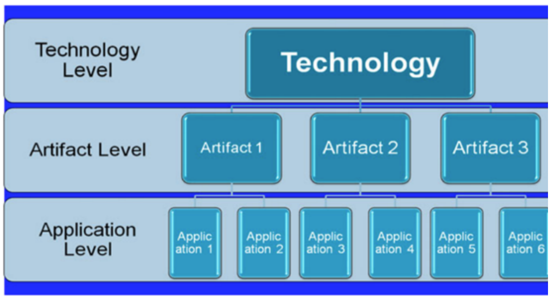

Figure 5 Brey's levels

This paper shows that application areas may significantly differ between the dimensions. Therefore, we would need to define the different subcomponents to its best use.

2.3.3 Business readiness levels

To get a more in-depth insight into the level of maturity of a particular business venture, the innovation project of Richie Ramsden and Mohaimin Chowdhury (Chowdhury, Aug 2019) [xviii] came up with a complimentary to TRL. This is the Business Readiness Levels, which would help the user identify the level of maturity of a business venture or innovation project. What the 9-step product readiness scale, as shown in Figure 6, helps us to achieve, is answering the questions about the readiness of the particular product's market. This scale shows the current state of the product between the original idea to a product mature enough to be feasible in the market.

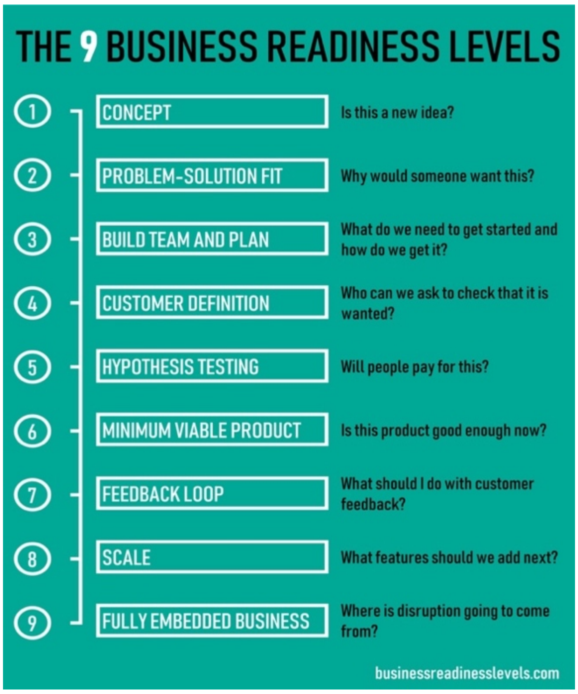

Figure 6 Concept Business Readiness Levels

However, the problem with BRL is that it does not answer questions about what happens when the product is ready, such as will it stay effective and deal with the potential problem of market changes and new entrants.

2.3.4 Social

A similar approach is defined by the innovation fund of Denmark, where it measures the level of societal adaptation of a technology, also on a 9-level scale, shown in Figure 7.

Levels
SRL 1 – identifying problem and identifying societal readiness
SRL 2 – formulation of problem, proposed solution(s) and potential impact, expected societal readiness; identifying relevant stakeholders for the project.
SRL 3 – initial testing of proposed solution(s) together with relevant stakeholders
SRL 4 – problem validated through pilot testing in relevant environment to substantiate proposed impact and societal readiness
SRL 5 – proposed solution(s) validated, now by relevant stakeholders in the area
SRL 6 – solution(s) demonstrated in relevant environment and in co-operation with relevant stakeholders to gain initial feedback on potential impact
SRL 7 – refinement of project and/or solution and, if needed, retesting in relevant environment with relevant stakeholders
SRL 8 – proposed solution(s) as well as a plan for societal adaptation complete and qualified
SRL 9 – actual project solution(s) proven in relevant environment

Figure 7 Social TRL[XIX]

What we can learn from this is that stakeholders and the environment are the ones to take into account. It is necessary to identify how to align such innovation with the stakeholders and the relevant environment. In this way, the product will be accepted by society and be able to be used.

2.3.5 Legal

The Legal readiness of a particular endeavour is hard to define. However, we can easily define the term itself as the dictionary of law states: "according to law, not in violation of law or anything". Therefore, we would need to figure out what the rules are in the Netherlands.

2.3.5.1 Rule of thumb

PWC came up with a rule of thumb for what you are required to fly commercially, which says to perform commercial flights need to pass practical and theoretical tests and receive permission for flights in particular areas.[1xix]

2.3.5.2 Commercial rules

In addition to the general rules for flying a drone in the Netherlands, commercial drone operators must follow these guidelines as well. "Commercial drone operations in the Netherlands require the drone pilot to hold a pilot's license, and the company/organisation overseeing the operation to hold am ROC permit to fly. If you operate a drone weighing no more than 4 kg, you may apply for a light permit." In addition, drone insurance is required for commercial drone operations in the Netherlands.[xxii]

Besides, if you earn money with your drone, you must comply with the rules for commercial use of drones. You will also need certain licences. This is how the government ensures that drone use is as safe as possible. [xx]

To measure Legal readiness, we will have to look at the multifaceted and intricate subcomponents such as the safety, privacy and environment. This is reflected in the Space 53 tool.

2.3.6 Conclusion dimensions

Learning from theoretical background and supplementary Readiness level models, we can derive each particular dimension at which stage the product is between the idea and observation of the actual fruitful implementation of the product. Furthermore, it is crucial to focus on the different aspects of a particular product since this can differ substantially. Therefore, I deem the Space 53 tool a great fit to answer the readiness of drone inspection market. However, it does lack clear links with the theoretical background, and therefore, my knowledge should help fill in the gaps.

2.4 Conceptual framework

A similar approach as the aforementioned drone readiness index research [X] would be applicable to my research where rather than looking at the bigger picture, the readiness of drones internationally-focused could be used instead to focus on the Netherlands and the respective inspection of renewable energy sources. This is where the Space 53 quick scan tool comes in, which already established the Technical business readiness level and Ethical legal and social (ELS) as the most critical dimensions. This is mostly in line with the previous readiness methods, but the new Space 53 framework does not only entail the overall readiness. It has a more specified and including nature due to the accountability of different specialised attributes which might otherwise be missed by other the basal frameworks. Therefore, this thesis adopts the framework of Space 53. An easy representation of the dimensions of the Space 53 tool are shown in Figure 8.

Figure 8 Easy representation of dimensions

3. METHODOLOGICAL APPROACH

3.1 Research approach

I will answer the research question and the implications for the further development of the field with the Space 53 tool. To map out the implications of the development, and see where improvements can be made, I need to find out where the challenges lay in the different fields as some fields might be holding the whole market and/or business back.

To find this out, I will use a quick scan tool developed by Space 53: "a public-private partnership – a single, shared portal for national and international organisations." [xxi], a partner of the University of Twente, which would also be the client of this particular thesis. This tool gains insight into the state of readiness of different dimensions, namely:

- Technical readiness level
- Business readiness level
- Ethical readiness level
- Legal readiness level
- Social readiness level

The tool will be used to assess different companies and their drone applications. The results, in turn, will be used to assess the state of the drone market from the view of different people in the renewable energy sector. By performing focussed interview questions based on the results, I will figure out why these lower scores emerge. To further answer the research questions, I will use the dimension tool as mentioned earlier, supported by literature and qualitative research in the form of interviews with contacts in the sector to identify where the strength and weaknesses lie.

3.2 Research design & strategy

To gain insight into the maturity and the state of the market for drone technology, I need to not only look into the literature of the subject to gain a deeper understanding, , but instead enter the field and get in touch with the people who are trying to push and deal with the drone market. Therefore, the following steps of the research have been made.

1. First, I want to understand and research my field.
2. I will find and contact experts in the renewable energy sector.
3. Then I would like to apply the scan tool on the self-contacted field experts and their businesses.
4. I will map out the state of the particular business and see where improvements can be made using the aforementioned readiness levels from the provided tool, which means assessing the individual values that the scan provides.
5. After that, I would like to have a qualitative, somewhat structured interview with these particular field experts to clarify where improvements for further development could be made, which in turn, I will elaborate on in the report.
6. Finally, I will conclude my findings on the maturity of the field and write out my discoveries about the possibilities and challenges of drone technology in the renewable energy sector.

Given the small sample size and research approach, this research is exploratory in nature.

3.3 Participants

Due to the particular nature of this research, I looked at companies in the renewable energy situated in the Netherlands. These partners needed to comply with the following requirements:

- Be in the renewable energy sector.
- Possess physical renewable energy sources to potentially inspect.
- Have an affinity with the subject product of drones.

After setting the requirements, I contacted partners which work or have worked on projects in the Netherlands with similar but differentiated backgrounds.

3.3.1 Boskalis

Andre Andringa is a project director at Boskalis Offshore Energy division. He has over 25-year experience in managing projects in civil engineering and sustainable energy and has been part of a multitude of offshore wind farms, and all the regulations and battles that come with these. The relevance of Boskalis as a partner for the research is the offshore windfarms which would benefit from the use of drones due to the hard reachability and safety risks that come with the inspection of these farms.

3.3.2 Falcker Innovations B.V.

Falcker Innovations BV is a forerunner in the field of software tools for inspection, which according them helps to detect asset deficiencies and degradation allowing for quantitative insight to improve asset life cycle planning, ROI and reduce environmental risks." The relevance of this partner is that they are doing a wide array of missions inspecting.

3.3.3 Brandsma digitaal Meten (BDM)

Brandsma digital Meten does the inspection of wind turbines and solar panels. They are able to precisely measure defects and wear and tear that comes with the construction. They are doing check-ups on solar panels regularly.

3.3.4 DroneQ

DroneQ has been doing inspections for over 20 years. They have a vast knowledge background as they state: "experienced in organising and executing complex international UAV project management, from both operational and financial perspective where the interests of all stakeholder are security safeguarded and DroneQ operates as a bridge between the various organisations involved." This makes them an interesting fit for this project.[xxii]

3.4 Follow up sessions

After the initial testing with the tool and the analysis of the received results. (see appendix) I get in touch again with the experts of three of the previous mentioned companies(excluding droneQ) to get their point of view on the results and discuss the steps to take to overcome the barriers and challenges and potentially raise the readiness levels. To further answer the research questions, I have prepared some overarching qualitative questions:

1. What do you deem necessary to further develop the field of drone inspection in the renewable energy sector as a whole?
2. What are the most significant benefits of using drones in your inspection sector?
3. How do you see yourself improving your current product to do better inspections?

4. What is holding back the potential adoption of drones in the renewable energy sector and especially yours?
5. How much do you see the market grow in the upcoming ten years?
6. Would you say the tool was useful to measure the maturity of the drone inspection in the renewable energy field? And do you have any recommendations to improve it?

By asking these questions, I will be able to discuss the limitations and possibilities further, and to help create more implementation and awareness of the state product.

4. FINDINGS

4.1 Findings Boskalis

The tool was completely filled in by Boskalis Offshore Energy, Business Unit heavy Lift (includes Offshore Wind) director Andre Andringa, the results of which pointed to an overall more than sufficient readiness for drone inspection in the sector of offshore windfarms.

Currently, due to the offshore nature of the drone inspection by Boskalis, I would argue that Boskalis is currently very ready for the use of drones.

Especially as the current way of inspection and getting to the wind turbines is, as André Andringa put it, 'extremely expensive and very dependent on the weather situations'. Seeing as the turbine has to be stopped and is not providing any energy at the moment of inspection, this results in a loss of profit. However, windmills are a product which has a life span of around 25 years, and any extension of that is extra gain and therefore profit. This is where drones can play a major role, especially in the late stage of a windmill lifespan (between 15 and 25 years), where maintenance issues and costs typically rise. Currently, drones can already be a great Technical Ready Tool (TRL 8) tool for measuring the build-up stage, which takes around 2,5 years. As André Andringa noted, the offshore industry is one that is very focused on safety which, as André put, '(…)results in a very boarded up and worked out **legal** (which is also reflected by the 8 scores from the tool), contractual and insured readiness'. Any innovation in that field is welcomed with open arms and therefore, there is no **social** (TRL 6) resistance due to being out on the sea. There is no public resistance probably due to the public not being bothered or implicated (8 out of 9 score) by these inspections. I would say based on these results that the use of drones in the offshore wind farms is very welcome and prepared.

4.1.1 Tool feedback and recommendations

André noted that giving more room for specific information about the user type would be beneficial fot the tool. Besides, adding a question about the level in which the person who fills in the scan is directly or from a distance connected to drone use in renewables would help a better understanding of the point of view on the results.

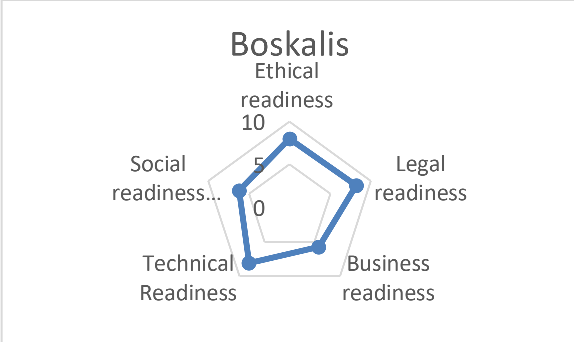

Figure 9 Results tool Boskalis

4.2 Findings Falcker innovations BV

Due to the expertise of the partner, we focus on the results of the social and legal tool.

What we learn from Falcker innovations and their results of the tool is that legal clearance is the most important factor that holds the inspection sector back. There is still much ambiguity (e.g. where can you fly) about laws and regulation. This is due to the fact that legal (7 on a 0-9 scale) measures keep being postponed and requests keep being stuck in an understaffed bureaucracy system. Therefore, it is necessary to figure out ways to provide the public with easily accessible information with easy to understand figures, tools and initiatives such the Drone Go application where you can see which professional drone is flying and what it is doing. Furthermore, the time gain, efficiency and the cutting out of human risks are worthwhile so much that drones are the future of inspection in the renewable energy sector. The market in the upcoming ten years is growing with more companies applying and adopting drone inspection and regulation in the Netherlands, catching up with countries such as Israel. Companies such as Falcker, which have a multiyear vision, will give insight and recommendations to organisations such as Jarus which push "a single set of technical, safety and operational requirements for the certification and safe integration of Unmanned Aircraft Systems (UAS) into airspace and at aerodromes"[xxiii]. When it comes to the technical preparedness of the company, their drones are CE certified (TRL 9) and are deemed as ethical, by always contacting stakeholders about the missions and already having done the paperwork and flight plans mapped out before setting flight. Furthermore, Falcker noted that every mission conducted almost never influences the public in an intrusive manner by setting out flights plans which should not harm the public, except for some unfortunate incidents where people are present where they should not be. This also means socially speaking (5.4 TRl on a 1-9 score) mostly the people directly involved with the project experience the drone effect, but as you can imagine, don't deem it a nuisance due to their work nature. However, we have to note there will always be people who might be upset by drones as the Netherlands is a moral bound country which again asks for regelation and awareness.

Legally speaking, there are a few cases in the Netherlands where pilots failed to adhere to safety rules, especially in the case of focused missions scenarios where potential (environmental) hazards are present such as:

- Crashing and the burden of the harmful hardware/batteries
- Crashing in water

These hazards still outweigh the risks and drawbacks that come with manned helicopter flights. When it comes to the liability of drones, maintenance is done by certified companies which are contactable when needed and can be held responsible should the drone have malfunctioned.

Figure 10 Results tool Falcker

4.2.1 Tool feedback and recommendations

Falcker noted: no matter which field of drones you fly in the social and legal will be the same. Besides, the tool does help to show you how the market is. Finally, the legal tool can help to fight ambiguity in regulation and further improve it by mapping it out.

4.3 Findings BDM [2]*

BDM sees drones as the future for inspection, as the machines improve the level of yield coming from solar panels by identifying malfunctions of the solar panels using thermal imaging. Within the next 10 upcoming years, the machines (read: drones) will learn to recognise things themselves even better. However, Roel cited that the inspection of solar panels dirtiness levels has a 'competitor' which are self-cleaning panels. When asked about the benefits of using drones, Roel stated:

- Drone as an eye in the sky just sees more and has a bigger overview;
- Measuring things from the things is so much more detailed;
- It is a way safer, and it is faster. The drones just get up there;
- Instead of day to inspect it just takes half an hour.

When asked about improvements in drone inspections, Roel noted that machine learning will be the next big thing in drone inspection. According to him, drones and the need for the market have to be a bit more mapped out and transparent with companies being open about their actions with drones. With Roel having a quote which basically sums up the maturity of the market "it's in the beginning of something". Therefore, regulations and rules need to be more worked out, so drone pilots know what they are up too and what is allowed, and ambiguity needed to be eradicated. (6 out 9 scoring scale)

When pushed on the question if he deemed their current drone operations as ethical, he noted that there is a lot not clear on the intrusiveness on people saying that "it's just something that people needs to get used to and has to be normalised, as people get still drawn back by them". However, he noted that concerning solar panel inspection that there are not that many problems with the public and that this will only get better seeing that future software will automatically be able to block people out (machine learning). When asked about how to improve ethical conduct, he put it as long as the certification allows it, and the pilot takes his responsibility no ethical issues should arise.

Socially (score:5.5 out of 9) speaking: when asked if there could be any improvements on the design and traceability of the drone, he noted that the company name is on the drone and the GPS is very accurate which results in easy traceability. Legally (score:6 speaking: currently, the use of drones is not that intrusive, but only in cases of solar panel in urban areas where solar panels are installed on supermarkets. Liability and tort wise BDM said that they are compliant and adhering to the rules. However, there is still a lot of ambiguity between different rules which results in uncertainty on what is allowed for the pilots. Luckily as it currently stands, there are not that many mistakes made by the pilots.

4.3.1 Tool feedback and recommendations

As feedback on the tool, he mentioned that privacy wise they were not as far as he thought they were which called and deemed it as one the most important in helping the field of drone inspection further. Seeing as the partner from BDM was mostly focusing on the operational aspect of drone inspection, he decided to skip on the business tool, however, noting that the business for drone inspection will only grow.

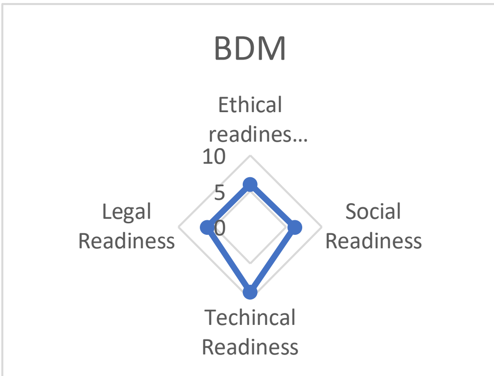

Figure 11 Results tool BDM

[2] *BDM has filled provided 4/5 of the dimensions excluding business seeing as he did not feel as the right man to answer this.[2]

4.4 Drone Q

Seeing as DroneQ could not be reached for a follow-up, I have to base my findings on the tool. Scores for Ethical a 7 on a 1 to 9 scale. This score is high in comparison to the other companies. However, it is noted that there still can be moral improvements made to mitigate legal risks and that in the case of drones influencing the public daily is not applicable in their application. Furthermore, another interesting point is that media attention can lead to unrest within other sectors.

Social (5.95 on a 1 to 9 scale)

What stands out again with the results of DroneQ is that they do not perform tests yet with all stakeholders in comparison with other parties. The design does not show what the drone is doing or its function and can, therefore, be improved. However, the drone is sufficiently accepted by the public, which again is in line with the drone application not influencing the general public.

Technical (6.17 TRL)

Except for drone management, the drone seems to be at least demonstrating the critical functions of the element in its relevant environment. Furthermore, the drones are currently doing a wide array of missions.

Business (8 TRL)

High overall scores, however, there are currently not that many measures taken to deal with potential substitutive technologies that solve the same customer and technical needs such as self-healing products.

4.4.1 Tool Feedback and recommendations.

DroneQ stated the tool has a comprehensive and good user interface. He wanted more examples which could be handy with complex tests which is something that also came up with the other participants.

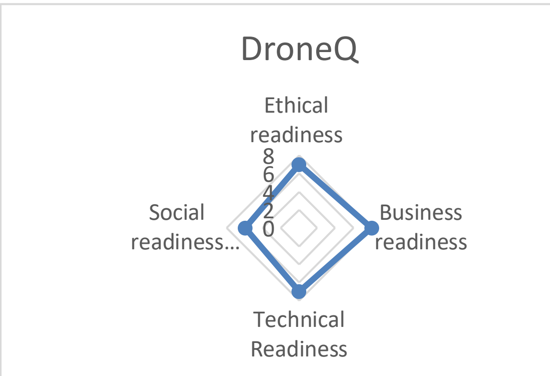

Figure 12 Results tool DroneQ

3 **Not every tool dimension was filled in by every partner.

4.5 Findings on the tool

The common themes that come with the results and feedback on the tool are:

- The social and legal tool are most worthwhile in helping the field of drone inspection further;
- Some questions are deemed irrelevant by the participants (and were therefore left blank);
- The tool is very confrontational about which still needs to happen and how new the market is;
- No matter which drone field you are in social and legal is mostly the same;
- More questions are needed about the current state of legislation in a country and if there are currently projects to improve this such as JARUS;
- Give more room for specific information about the user type and the order in which the person who fills in the scan is directly or from a distance.

Considering market developments, the tool should focus more on dimensions which are holding drone implementation back, such as social and legal dimensions and give a little bit more room for people higher up in the chain of companies which could use the drone technology but do not know every detail but look at the bigger picture. Furthermore, as someone who worked with the tool extensively, I recommend adding a function so you can see when you go back to the tool selection which tool dimensions you have finished. Furthermore, for data analysis, add clear pointers what the eventual TRl scores and scale scores are.

Table 1. feedback on the tool compared with other students.[3]

	Medical Transport	Inspection of Renwable Energy Sources	Total
	n = 1	n = 4	n = 5
Technological	4.4	3.1	3,4
Business	4.4	3.3	3,5
Ethical	1.0	2.7	2,4
Legal	4.2	2.7	3,0
Social	3.8	3.1	3,2
Overall scan	4.0	2.8	3,0
Overall	**3.6**	**3.0**	**4.0**

Furthermore, you can see from the results of the averages of the tool that the maturity for the inspection using drones is somewhat sufficient if you take the averages.

5. CONCLUSION AND DISCUSSIONS

For this research, I constructed the following research question: "What is the state and possibilities of drone technology in the renewable energy inspection market and what are the implications that come with the further development field?".

- What is the maturity state of this field across multiple dimensions of technology acceptance?
- How can these dimensions be developed in practice and what are its most important challenges?
- What are the benefits of the inspection of drones in the renewable energy sector?
- How can we further develop the Space 53 tool?
- What's holding back the inspection of drones in the renewable energy sector?

The current state of drone inspection can be seen as the next step for inspections in the renewable energy sector as a whole, seeing that all of the participants in this research noted it as a safer, cheaper and faster way of getting the information needed to keep the energy sources running and even going as far as possibly extending the life span of said sources resulting in more profit for the **business**. As noted by the participants, currently, the drones are already very **technical** ready and operational and have been showing very promising results in the sector. In the upcoming years, it will only get better due to the machines getting smarter and more autonomous due to innovations that come with the rise of machine learning. This will help mitigate potential social and privacy issues which the machines will effectively be able to cut out of the data they gather. However, what the participants and the results of the test keep showing is that there is still a lot of ambiguity and uncertainty in the regulation and **legal** matters, as the participants believe that the regulators still have not caught up with the fast and massive possibilities that come with drone technology due to a slow and understaffed bureaucracy system. Nevertheless, Air Traffic Control authorities in the Netherlands (LVNL) are working on services such as Go Drone which should be able to show where drones are allowed to (possibly) fly if the current fly-area block is free and the aerospace allows it. However, as noted by the participants and news articles, the app is confusing[xxiv] and causes a run to get fly area blocks which are needed to be able to fly your mission. Next to the Legal drawbacks, the **social** dimension is also somewhat holding back the further adoption of drone technology in the field. This is due to the public being misinformed, ambiguity about drone use and the potential nuisance that comes with them. This is where the government and parties such as JARUS need to come up with easily accessible information, so suspicions of the public can be dealt with. However, as in the case of most applications with wind turbines and solar panels, the public is not implicated or affronted by the use of drones which means that **ethically** as long as safety measures are adhered current drones operations in the sector could be maintained. To help map out the cruxes and the problems with the current drone applications, tools such as the Space 53 tool need to improve in such a way that it is also accessible to people who are not directly involved with all aspects of drone technology applications. To making it more accessible you need to have clear examples and constructive feedback so the field can grow even further by mostly figuring out how to improve the legal and social dimension.

As a final note, drone inspection is the next step for renewable energy inspection and will only keep improving. However, only time and effort by the government and the drone users and their experiences will make the market mature.

5.1 Limitations and future research

Seeing as this research is relatively broad it gives an overview of a wide market with a multitude of applications and different kinds energy sources. Therefore, different focused research would help further the market especially that would focus on the social and legal dimensions and on how to make drones more accepted with awareness campaigns and improved drone designs. What has limited this research relatively small sample group and the data gather by the tool however I do believe due to the follow ups it says a lot about the market.

5.2 Acknowledgements

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APPENDICES

1. APPENDIX VARIABLES TOOLS

1.1.1 Technical readiness level

In the technical readiness dimension of the tool, we measure the readiness level of 5 sub-components, namely:

- Total system configuration
  - Meaning that the system is proven to be successful and certified and therefore able to buy
- Drone management components / functions
  - Meaning the functionality of the hardware parts of the drone and its functions
- Flight components / functions
  - Meaning the software used for flight control and flight-related communication and control
- Application components / functions
  - The components used for the possible applications of drones
- Systems integration
  - The combining of the different components.

1.1.1.1 Implications:

If the system is not able to function correctly and be integrated, the product will have no foot to stand on and or even work.

1.1.2 Business readiness level

- The customer
  - This subcomponent is about the potential problems and benefits and willingness of customers to participate in drones.
- The value propositions
  - The identification, formulation and communication of the value proposition for drones.
- Market forces
  - What possible threats and bargaining powers do the other players have and are there measures taken to counter this.
- Alliance partners
  - The level of collaboration with other partners
- The value delivery process
  - Defining of methods and contacts between partners about product control and specification and the capability of the organisation to adapt and supply
- Financials
  - Clear view on cost and revenues that come with drone application and accompanied services and the viability of drone application.

Implications

If there is no market or profit for drones or will not be created, the drone will never see the light of day.

1.1.3 Ethical readiness level

Purpose

- Is about the morals doubts and desires and resistance that come with the field of drones

Safety

- The reduction and sense of risks

Automation

- The autonomy of the drones' function and support and the moral responsibility that go with it

Distance

- The distance between the physical and mental and the problems and judgements that come with it

Value shifting

- The measuring of the dynamic rules, acceptance and responsibilities that come with the field

Implications

With technologies as drones which are intrusive and hard to control or take out by other parties once in the air. Ethical questions as loss of privacy, nuisance and even danger arise which might scare away people from the introduction of these and if it is even moral to have these machines out there.

1.1.4 Legal readiness level

- Public safety
  - The measurement of the safety of the public in the Space on the ground and the involved parties
- Environmental burden
  - That comes with the use of drones, e.g. energy pollution noise and scarce material and the disturbance of natural habitats and animal lies
- Privacy
  - Dealing with the impact on private Space.

Implications:

As mentioned before the problems that drones might create can cause regulation to take such a form that the machines will not be able to operate correctly anymore.

1.1.5 Social readiness level

- Stakeholders
  - Identification of stakeholders
  - And what are the uses for drones for them and the requirements and wishes
- Design
  - What is the visual and acoustic appearance of the drone?
  - What are the planned human-drones interactions?
  - What is the role of stakeholders in the decision?
- Acceptation
  - What are the benefits of the drones, and what are the risks that come with it?

Implications

Drones have to fit in and be accepted by society the use of these machines for their applications.

Otherwise, they might not be able to operate.

2. APPENDIX PROTOCOL

The research will answer the question "What is the current state and possibilities of drone technology in the renewable energy inspection market and what are the implications that come with the further development of the field?". This question will be answered by three things, Literature review, The tool and interviews. The last two is where you as a participant come in. The tool is an extensive questionnaire with the aim of providing insights into the development and or use of a drone. The Space53 Quick Scan Tool will monitor a drone application by means of determining so-called readiness levels for five domains: technical, social, business, legal and ethical. The test will directly give results which you will be able to download to potentially personally review. Once you filled in the test, please reply to this email so I can start analysing the results and come back to you for a follow-up meeting/interview where we will discuss the steps, we could take to overcome the barriers and challenges to potentially raise the readiness levels.

To do this, I have prepared some overarching qualitative questions, namely:

1. What do you deem necessary to further develop the field of drone inspection in the renewable energy sector as a whole?
2. What are the most significant benefits of using drones in your inspection sector?
3. How do you see yourself improving your current product to do better inspections?
4. What is holding back the potential adoption of drones in the renewable energy sector and especially yours?
5. How much do you see the market grow in the upcoming ten years?
6. Would you say the tool was useful to measure the maturity of the drone inspection in the renewable energy field? And do you have any recommendations to improve it?

These questions will be complemented with questions about the lower results score of the scan tool after the initial results, which will answer the following questions:

• Why did this lower score occur?

• What would be solutions to solve it?

• Is it holding the adoptions of drones in the renewable energy sector?

The meetings will be held via conference calls, which I will set up for you in such a way that it should not waste any unnecessary time. These interviews will be recorded and transcribed, so I will be able to finish my research and give an answer to the research questions. This all will be done in accordance with the ethical rules of academia from the University of Twente, and you as a participant will always be able to withdraw from the research without having to give a reason. However, I am very happy with your cooperation due to the relatively small but essential group of participants with your expertise within this particular niche.

Thank you again for participating in this research and helping to further academics and the field of drones.

3. APPENDIX TOOL SCORES

Boskalis

Ethical	8
Social	6.2
The stakeholders	7
The design	4.2
The acceptance	7.4
Legal readiness	8.2
Score public safety & security	8.5
Score environmental burden	7.4
Privacy	7.3
Data protection	9
Liabillity	9
Business	5.8
The customer	9
The market	3.5
The business network	3
The process	6.4
Financials	5.7
Technical	8.1
System integration	9
Drone management	7
Score flight	7.5
Flight components/funtions	7.5
Application components /fucntions	8
backend processing	9

BDM

Ethical Readiness	6.00
Social Readiness	6.2
The stakeholders	5.0
The design	5.8
The acceptance	5.8
Legal readiness	6.2
Score public safety & security	9
Score environmental burden	7
Privacy	3
Data protection	9
Liabillity	6.2
Technical readiness	9

Falcker

Technical	9
Social	5.4
The stakeholders	6.3
The design	4.8
The acceptance	5.8
Legal readiness	6.8
Score public safety & security	5.2
Score environmental burden	6.9
Privacy	7
Data protection	9
Liabillity	6.2

DroneQ

Ethical	7
Social	5.95
The stakeholders	4.0
The design	4.4
The acceptance	7.2
Business	8 (7.8)
The customer	8.5
value proposition	8.3
The market	7
The business network	8
The process	7.9
Financials	8.3
Technical	6.2 (7)
System integration	6
Drone management	4.3
Flight components/funtions	7.5
Application components /fucntions	8
backend processing	9