Whitepaper on UAM Service Availability

Examining 10 European Cities

UNISPHERE

Content

1. Motivation for Undertaking this Analysis

Urban Air Mobility (UAM) and Regional Air Mobility (RAM) are driving the transformation of the aviation industry through the implementation of new technologies in the areas of electrification, digitalization, and automation. During the past years Air taxi manufacturers have raised multiple billion Euros funding and are on the way towards type certification. To create new markets for urban transportation, an ecosystem is needed that includes not only aircraft manufacturers and operators, but also systems for a more digitized airspace and infrastructure to supporting the daily flight operation.

This white paper focuses on the impact of weather conditions on airline operations, which is critical to the selection of airline hub locations and the design of route networks within a city or between cities.

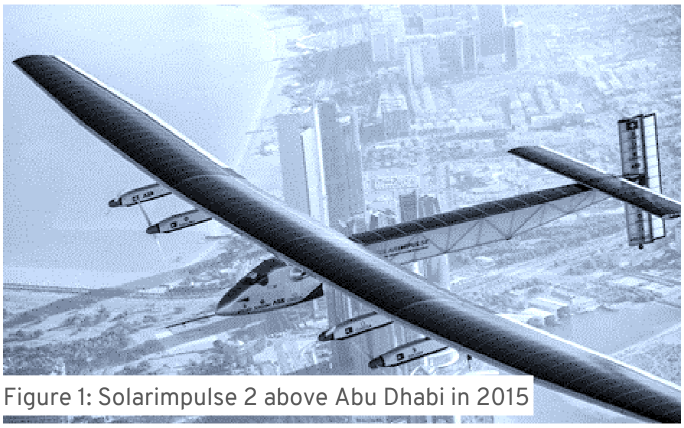
Figure 1: Solarimpulse 2 above Abu Dhabi in 2015

The initial idea for using simulation and evaluation algorithms to understand the prevailing weather conditions was already born during the *Solar Impulse project – the first solar-powered flight around the world*. For planning the flight around the world, the design of the route and the selection of suited airports was crucial, and the weather did play a key role since the Solarimpulse aircraft was much more sensitive to weather effects than conventional aircraft.

A large part of the Unisphere team was involved in the flight operations and mission planning of Solar Impulse. During this project, we learned that it is increasingly important to understand the operating conditions when using new technologies such as electrically powered aircraft, which must operate reliably from day one while having fewer "fuel" reserves than any commercial aircraft. With the advent of eVTOL, an understanding of weather impact on their initial flight operations is becoming more important to create a safe and commercially viable business.

Since commercial eVTOL operations are new to the world of aviation, there is a lack of experience to support informed decision making for critical infrastructures, such as where to place the vertiports? Or which are the initial routes that show a high service availability? Answers to these questions are important to ensure viable business cases for UAM services.

> *"In preparation of the first solar-powered flight with Solarimpulse 2, thousands of flight trajectories were simulated to identify the best flight path around the world. Limited energy reserves and the sensitivity of the aircraft for wind and turbulence forced us to rethink how to assess the suitability of airports at a global scale."*
>
> **Michael Anger, former Flight Director of Solar Impulse, CTO/Unisphere**

The objective of this analysis is twofold. On the one hand, the results should create awareness for the topic since many cities and companies have announced plans on building vertiports to enable UAM services. On the other hand, we aim at triggering a discussion on the weather parameters, the operational limits that should be considered, and the aircraft capabilities to improve the analysis, which will be extended to more cities and other continents in the next step.

If you are interested in contributing to this discussion, we are happy to receive your feedback!

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Based on the feedback, we will update the analysis for the European cities from this Whitepaper and extend the scope of the analysis to additional continents and cities.

2. Study Scope – Analyzing 10 Major European Cities

The Locations

The study covers a selection of 10 European capitals considering their metropole region. The cities are marked in Figure 2. The analysis focuses on metropole regions based on the assumption that larger geographical areas are one characteristic of early adopters for UAM services.

Within each capital, the study used the location of the main train station since they represent a connecting point for mobility and a uniform selection could be made for all 10 cities. The exact location coordinates are listed in the Appendix.

Figure 2: Cities analyzed in the study

Weather Data & Models

For the analysis, historic weather model data of different weather models covering Europe were used. Together with our providers, a downscaling of the horizontal resolution and data in 5-minute timesteps is achieved. The downscaling improves the coarse grid native representation down to a spatial resolution of 90m. This is achieved by applying high-resolution land usage data, soil, terrain data, astronomical computations & other sources.

Unisphere used a so-called *mixed model* which is based on the weather models listed in Table 1. Depending on the position of the point of interest (POI) the mixed model aggregates and combines data from the finest weather models available at the POI.

ECMWF-IFS	European Center Medium-Range Weather Forecast Integrated Forecasting System
NCEP-GFS	Global Forecasting System by the National Centers for Environmental Prediction
UKMO-EURO4	European model by the UK MetOffice
DWD-ICON-EU	German Weather Service DWD
MF-AROME	Meteo France
MM-SWISS1k	High-resolution model for Switzerland designed by Meteomatics
CMC-GEM	Global Environmental Multiscale model by the Canadian Meteorological Center

Table 1: Weather models that are the basis for the mixed model which is used for this study

Using weather models instead of weather recorded with weather stations has some disadvantages, but also some advantages: Using the models gives the flexibility to study every coordinate on the globe, and at every altitude. Whereas weather stations in remote areas are rare and installed on the surface only, which makes it difficult to judge weather conditions at 150m AGL, nor do they provide accurate information of winds, humidity, temperature, icing potential at altitude.

For this study, the best of both worlds was used, meaning wherever there were weather stations in the vicinity of the point of interest the output of the weather model was calibrated using the actual observation data of multiple weather station measurements nearby. That way the highest possible accuracy is achieved.

Weather Parameters & Classification

For assessing the UAM service availability 15 weather parameters were analyzed over the past three years (2018-2020) using historic weather data. The parameters were classified into *nominal*, *moderate*, and *severe* conditions, which are defined as follows:

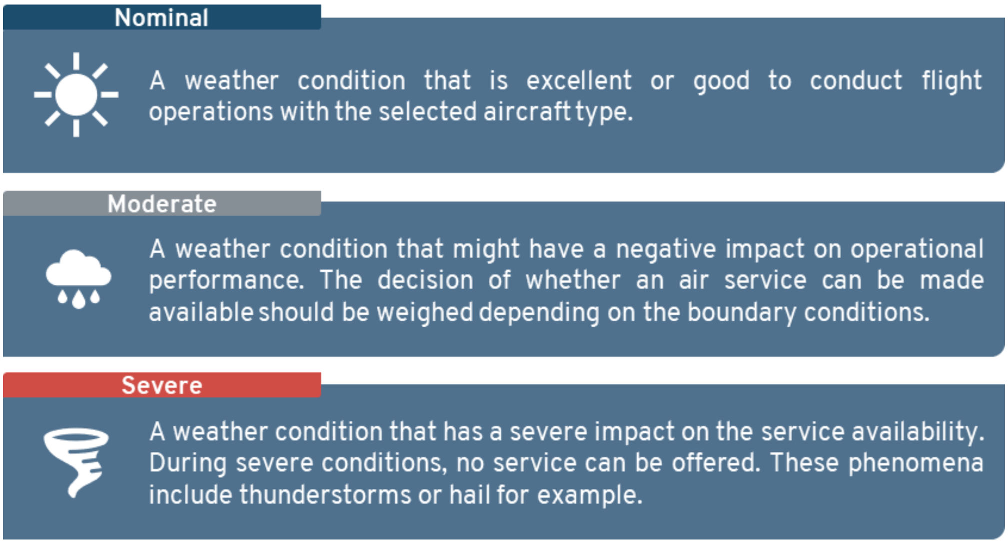

Figure 3: Definition of Nominal, Moderate and Severe Conditions

The 15 parameters are clustered into five groups of parameters, which are (1) Visibility, (2) Wind, (3) Temperature, (4) Precipitation, and (5) Dangerous Phenomena. Below, the classification limits for each parameter can be found.

WX Group	Parameter	Nominal	Moderate	Severe
Visibility	Visibility	> 5000 m	5000-1500 m	< 1500 m
	Ceiling	> 500 m	500-150 m	< 150 m
Wind	Mean Wind speed	< 15 kn	15-20 kn	> 20 kn
	Gust Factor	< 10 kn	10-15 kn	> 15 kn
Temperature	OAT range	-20 to +40 °C	-30 to -20 / +40 to +50 °C	<-30/>+50 °C
Precipitation	Rain amount	< 2.5 mm/h	2.5-7.6 mm/h	>7.6 mm/h
Dangerous Phenomena	Thunderstorm	Always classified as severe		
	Sand- or dust storm			
	Funnel clouds			
	Freezing rain			
	Squall			
	Ice pellets			
	Hail			
	Fog			
	Smoke/volcano ash			

Table 2: Weather parameters and classification used for the analysis

The Analysis – Method & Technology

For analyzing the weather conditions, we used elements of our Smart 4D Trajectory technology. The technology consists of:

(1) **Digital Twin Technology** that creates an accurate simulation of any air taxi or drone flight, considering aircraft performance models, operational limitations, terrain data, and high-resolution weather data, and

(2) **Smart Evaluation Algorithm** that automatically assesses the digital twin for weather risks, the overall flight feasibility, and derive a validated flight plan.

For the location analysis that was conducted in this Whitepaper, we used the Smart Evaluation Algorithms to automatically evaluate the weather data.

The weather data were evaluated on an hourly basis for the years 2018, 2019, and 2020. Given the timeframe and number of parameters around 400.000 data points were analyzed for each location. If in a given hour one of the parameters e.g. gust factor, was beyond the limit of *Nominal* it was considered as *Moderate* or *Severe*.

The operational conditions were analyzed at a height of 10m above ground level (AGL) using the digital surface model SRTM-30 (Shuttle Radar Topography Mission, 30m date). However, it is clear that the placement of vertiports on different heights of the actual installment, e.g., on rooftops or at ground level, must be considered to correctly model weather effects.

3. The Reference: Operational Availability in Europe

As a baseline, and to provide a common basis for assessing the individual cities in Europe, all European countries were analyzed. Figure 4 shows the percentage of time per year with nominal conditions for 12 selected countries in Europe. The 12 countries are composed of the country with the highest and lowest service availability and the 10 countries of the respective cities that were analyzed.

For the analysis, the 20 most populated cities of each European country [1] were analyzed for their operating conditions (based on 2018, 2019, and 2020 weather data). In total, 754 European cities were analyzed in this way. In order to obtain a reference value for each country, the results were averaged for all cities within a country. The 754 cities also serve as a basis for ranking the 10 cities analyzed in this Whitepaper.

With 87% nominal hours, the best operational conditions over a year can be found in Monaco, whereas Ireland ranks last with only 37% of nominal hours. This country value can be used to better contextualize the results of a particular city within the overall context of the country.

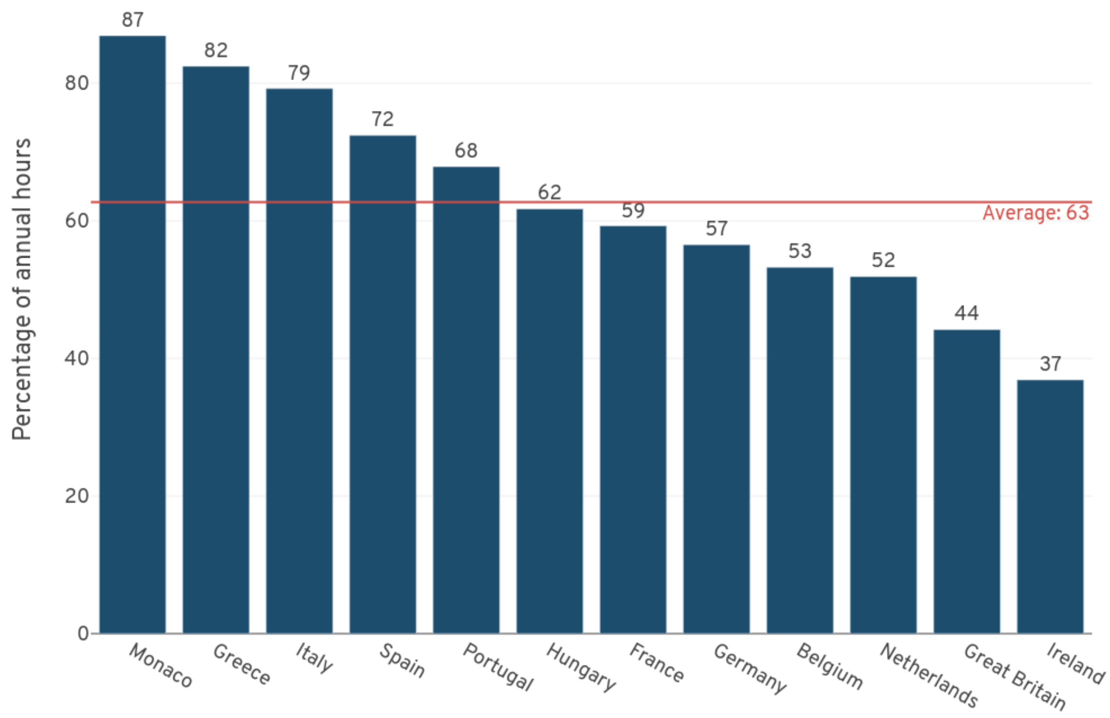

Figure 4: Nominal Conditions for UAM with Multirotor Concept in 12 Countries

4. Results – Metropole Regions

In this chapter, we will provide detailed insights into the operational conditions of the 10 cities that were studied in this report. Each of the cities will be described with the following diagrams.

1) **Overall availability:** A pie chart describing the overall distributions of the weather conditions according to the classification into nominal, moderate, and severe.
2) **Seasonal Impact:** A stacked bar chart distinguishing the different weather conditions by month to better understand the impact of seasonal effects.
3) **Reason for non-availability:** A bar chart with weather parameters that were causing severe conditions for more a detailed understanding of the reason for non-availability.
4) **The wind rose**: Wind rose that is indicating the cumulative distribution of wind direction and wind intensity.

Comparison of All Cities

Figure 5 shows the overall results of all ten european cities and the percentage of time within nominal conditions. Athens and Rome are leading the ranking with 83% and 84%, whereas London at given conditions only provides 50%.

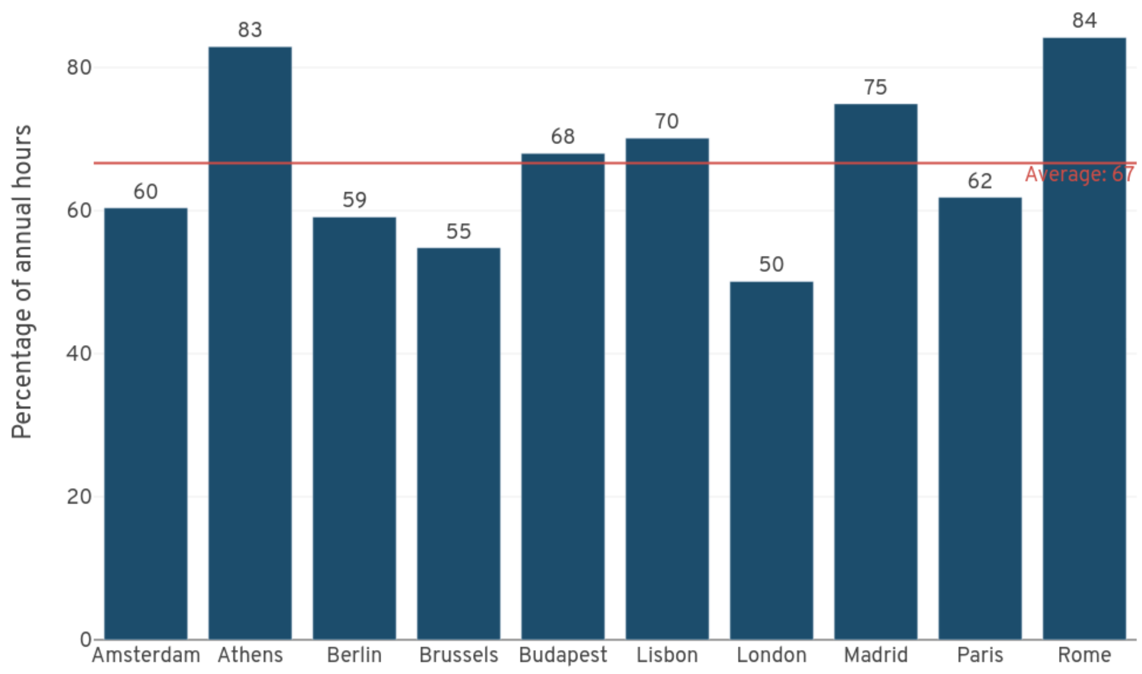

Figure 5: Comparison of nominal conditions for ten European cities

Amsterdam

For the city of Amsterdam, around 60% of the operational conditions are classified nominal (see Figure 6).

In total, 14.3% of the operational conditions are classified as severe. Out of 754 cities analyzed in Europe, Amsterdam ranks number 574.

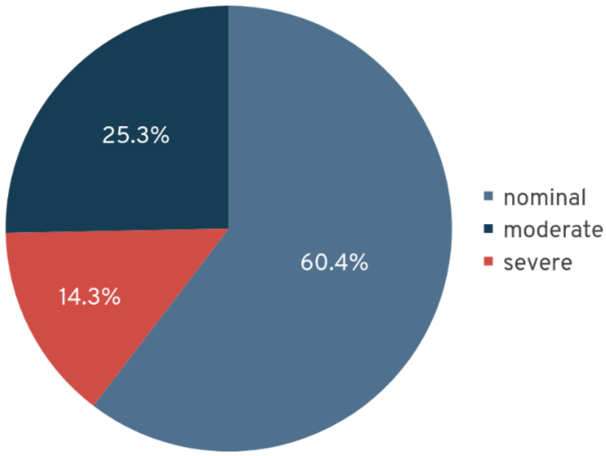

Figure 6: Overall Availability for Amsterdam

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a strong seasonal variation in terms of severe and nominal conditions. December is the month with the highest percentage of severe conditions and July is the one with the highest percentage of nominal conditions.

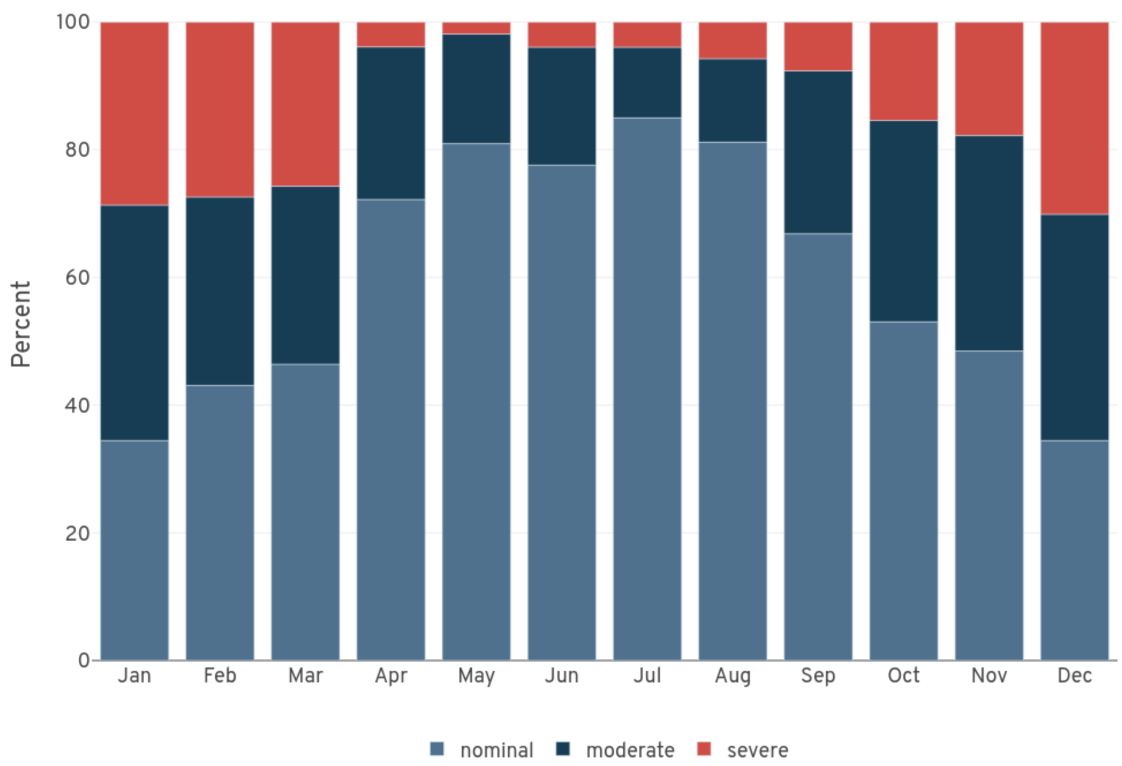

Figure 7: Seasonal dependency of operational conditions per month for Amsterdam

As shown in Figure 8, the predominant reason why weather conditions are classified as severe in Amsterdam is the weather parameter “gust factor” with 85%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on the wind and gust limits of an aircraft, this may vary.

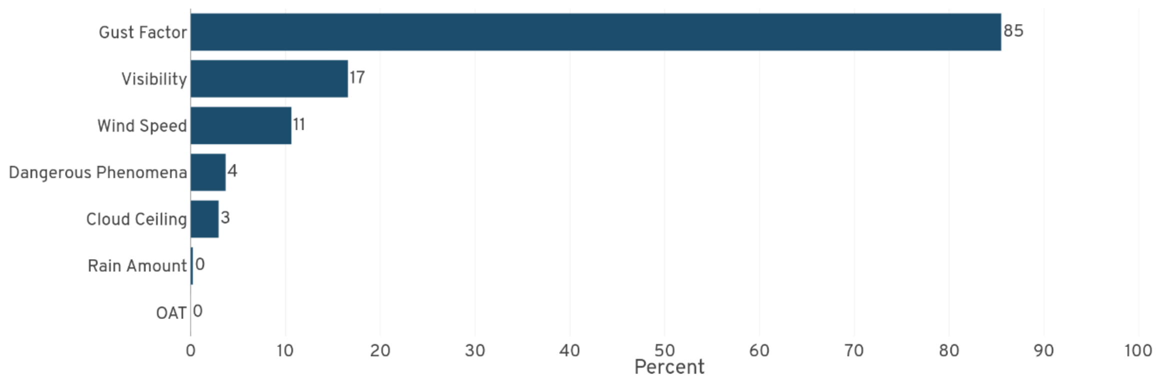

Figure 8: Main reasons for severe conditions, full-year for Amsterdam

The following analysis (Figure 9) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

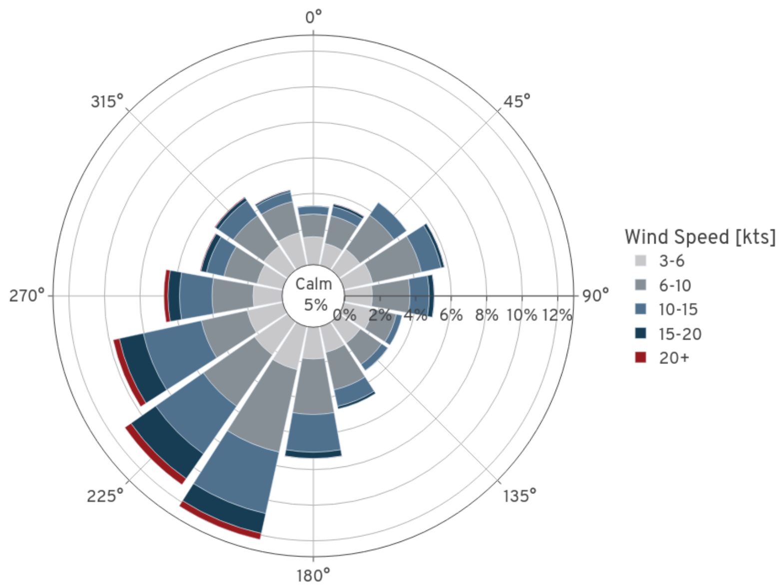

Figure 9: Wind rose day and night, full-year for Amsterdam

The dominant wind direction is South-Southwest. 5% of the time wind conditions were below 3 knots and calm. Whereas the majority of the winds are between 6 to 15 knots. This information is useful for the orientation of the vertiport or approach and departure trajectories of eVTOL.

Athens

For the city of Athens, around 83% of the operational conditions are classified nominal (see Figure 10)

In total, 4.3% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Athens ranks number 78.

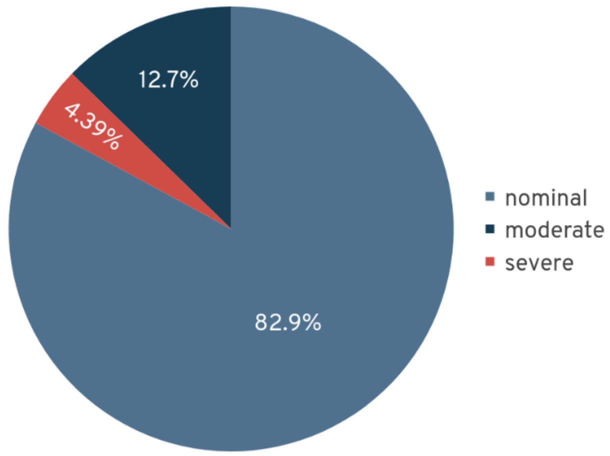

Figure 10: Overall Availability of Athens

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a smooth seasonal variation in terms of severe and nominal conditions. January is the month with the highest percentage of severe conditions and May is the one with the highest percentage of nominal conditions.

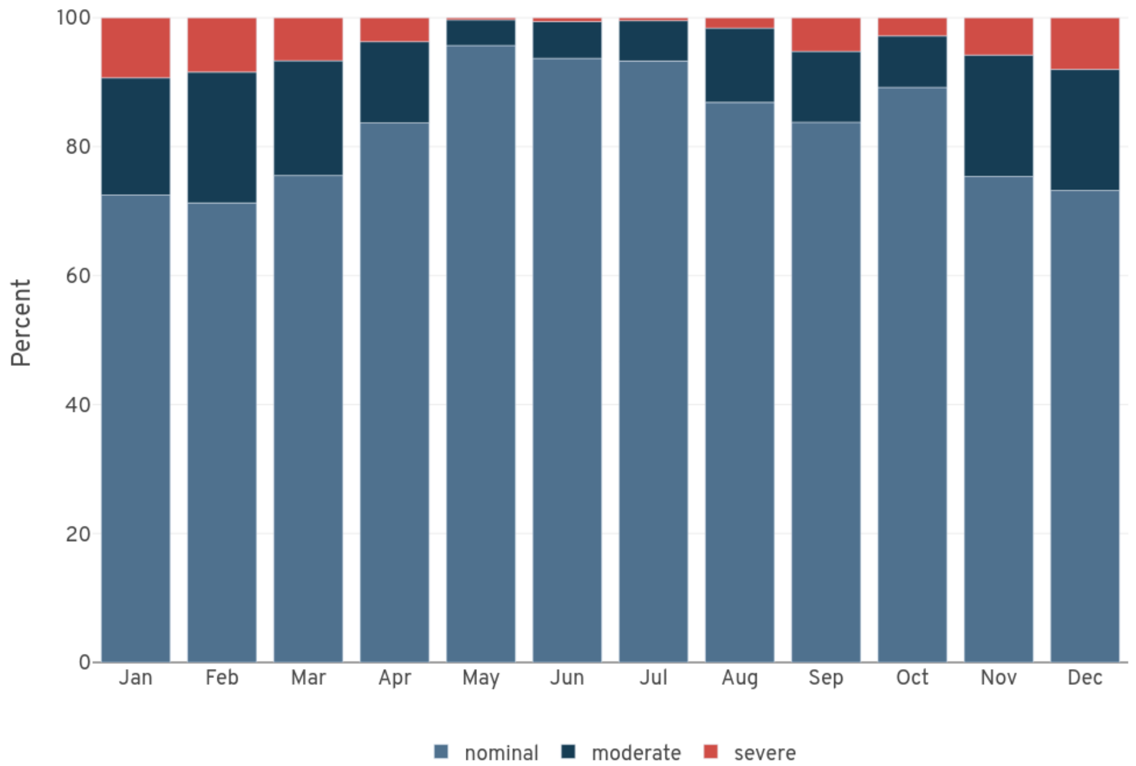

Figure 11: Seasonal dependency of operational conditions per month for Athens

As shown in Figure 12, the predominant reason why weather conditions are classified as severe in Athens is the weather parameter "gust factor" with 67%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on the wind speed and wind gust limits of an aircraft, this may vary.

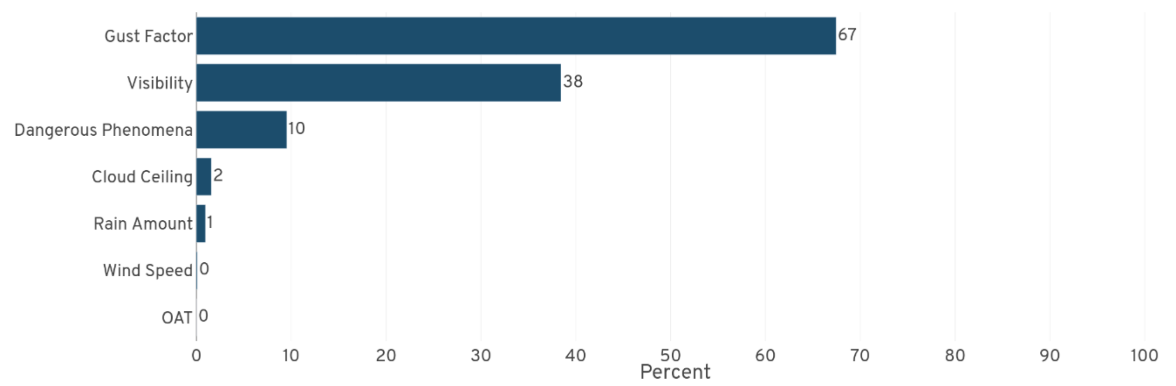

Figure 12: Main reasons for severe conditions, full-year for Athens

The following analysis (Figure 13) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

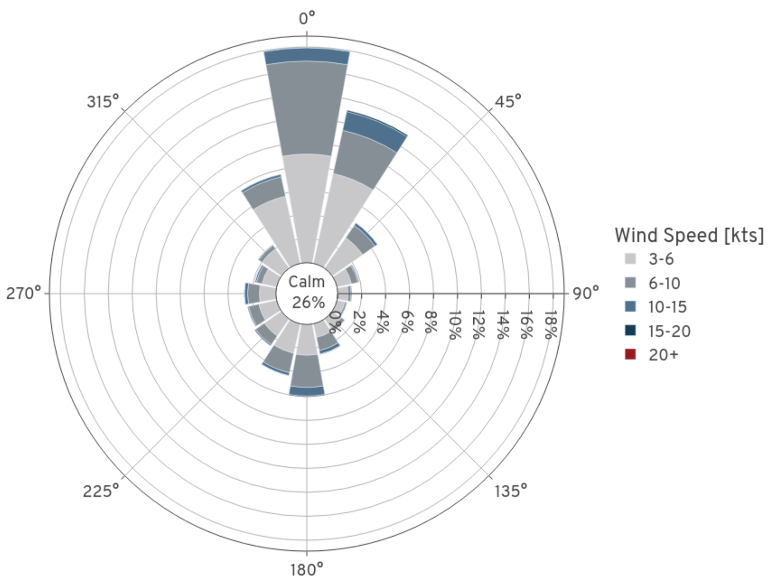

Figure 13: Wind rose day and night, full-year Athens

The dominant wind direction is North. 26% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 3 to 10 knots. This information is useful for the orientation of the vertiport or approach and departure trajectories of eVTOL.

Berlin

For the city of Berlin, around 59% of the operational conditions are classified nominal (see Figure 14).

In total, 13,8% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Berlin ranks number 435.

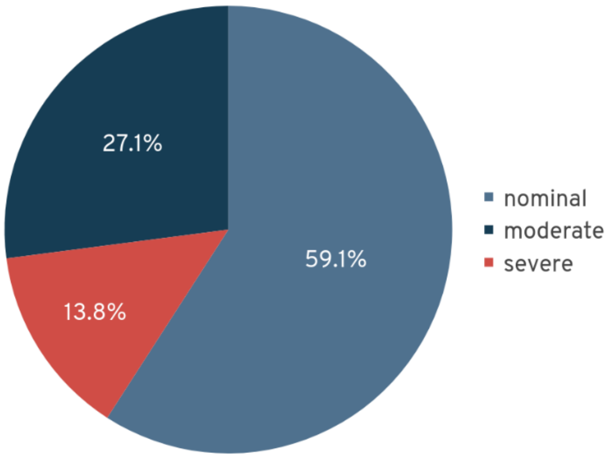

Figure 14: Overall Availability of Berlin

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a strong seasonal variation in terms of severe and nominal conditions. January is the month with the highest percentage of severe conditions and August is the one with the highest percentage of nominal conditions.

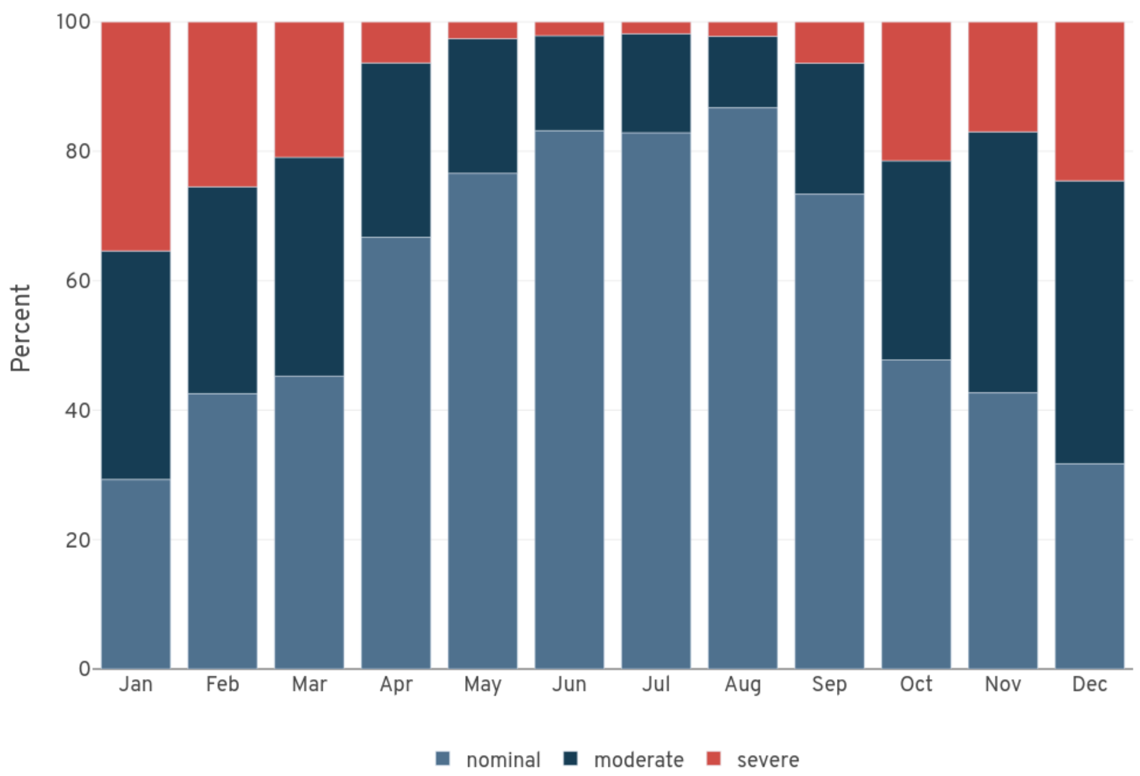

Figure 15: Seasonal dependency of operational conditions per month for Berlin

As shown in Figure 16, the predominant reason why weather conditions are classified as severe in Berlin is the weather parameter “gust factor” with 91%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on wind speed and wind gust limits of an aircraft, this may vary.

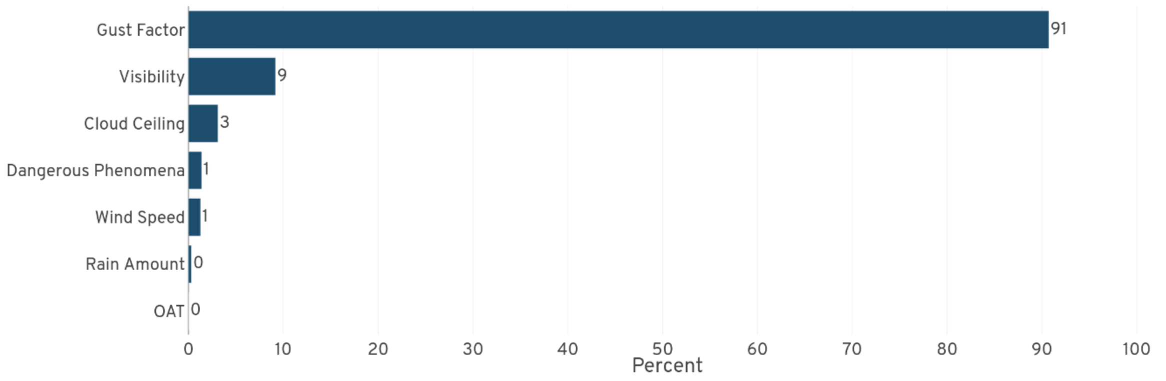

Figure 16: Main reasons for severe conditions, full-year for Berlin

The following analysis (Figure 17) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

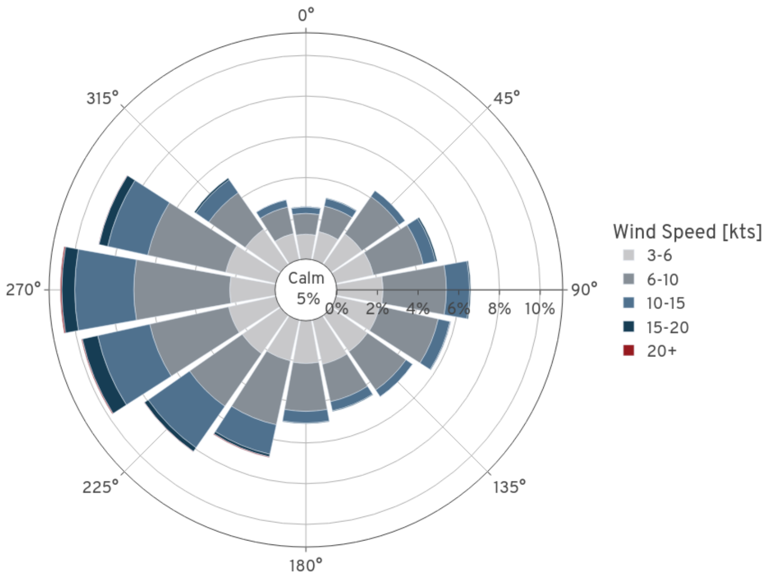

Figure 17: Wind rose day and night, full-year Berlin

The dominant wind direction is West. 5% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 6 to 15 knots. This information is useful for the orientation of the vertiport or approach and departure trajectories of eVTOL.

Brussels

For the city of Brussels, around 55% of the operational conditions are classified nominal (see Figure 18).

In total, 18,5% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Brussels ranks number 498.

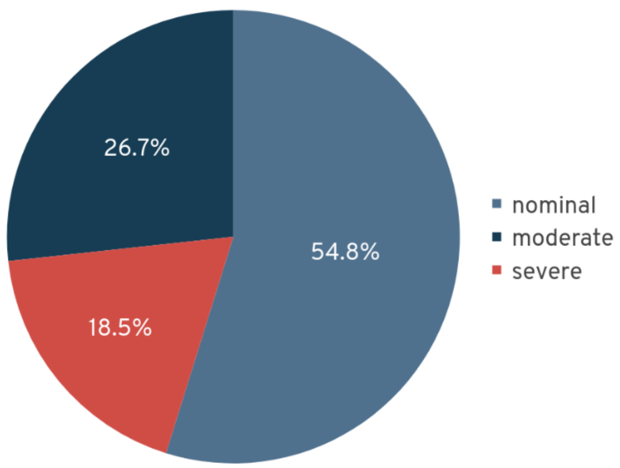

Figure 18: Overall Availability of Brussels

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a strong seasonal variation in terms of severe and nominal conditions. December is the month with the highest percentage of severe conditions and July is the one with the highest percentage of nominal conditions.

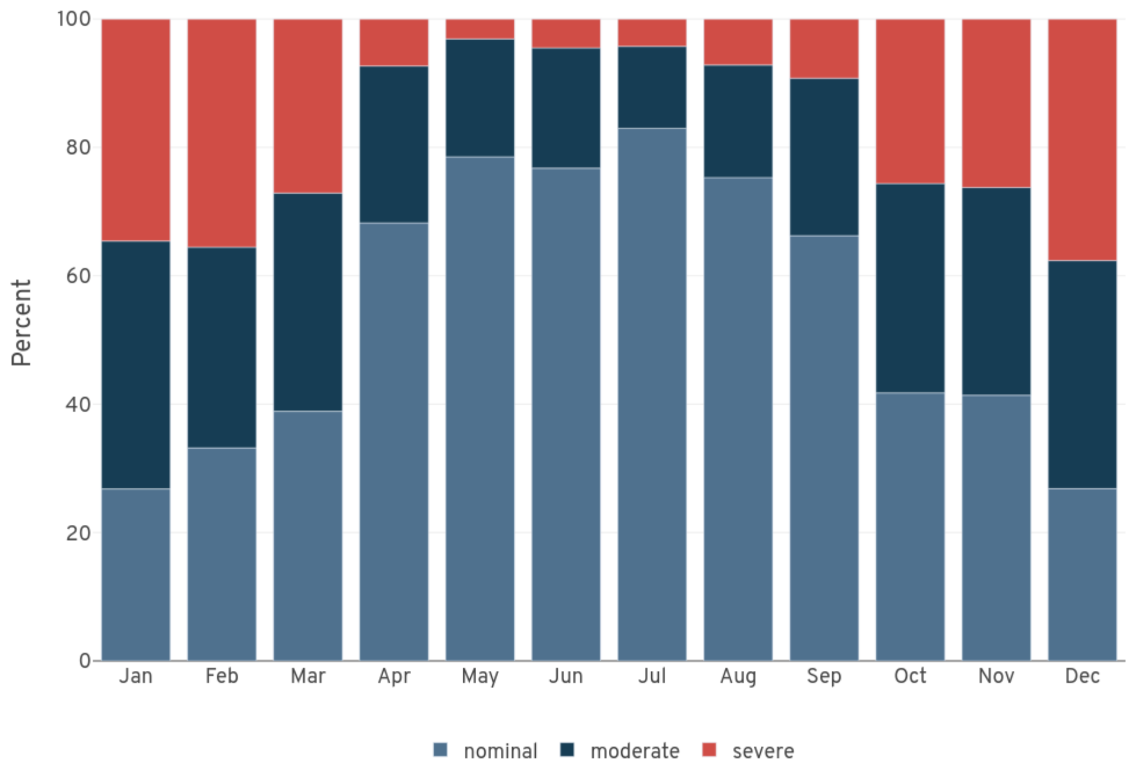

Figure 19: Seasonal dependency of operational conditions per month for Brussels

As shown in Figure 20, the predominant reason why weather conditions are classified as severe in Brussels is the weather parameter "gust factor" with 92%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and mean wind speed in the same period. Depending on the wind speed and wind gust limits of an aircraft, this may vary.

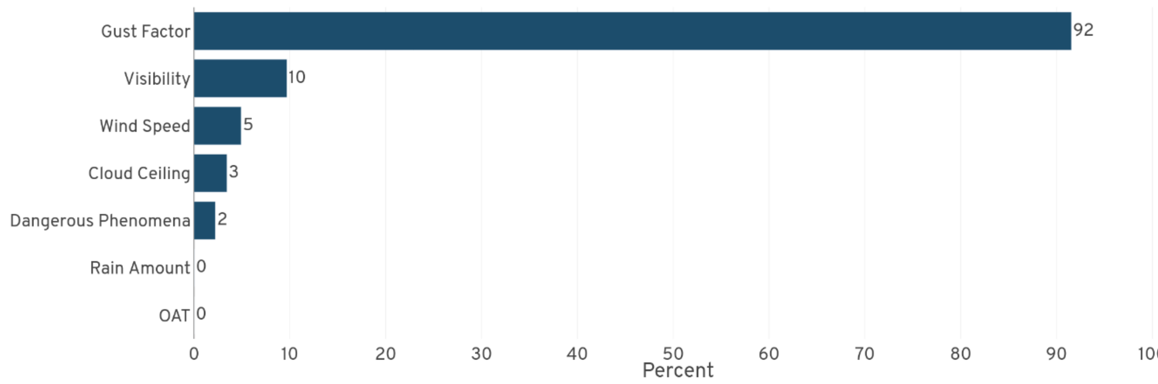

Figure 20: Main reasons for severe conditions, full-year for Brussels

The following analysis (Figure 21Figure 17) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

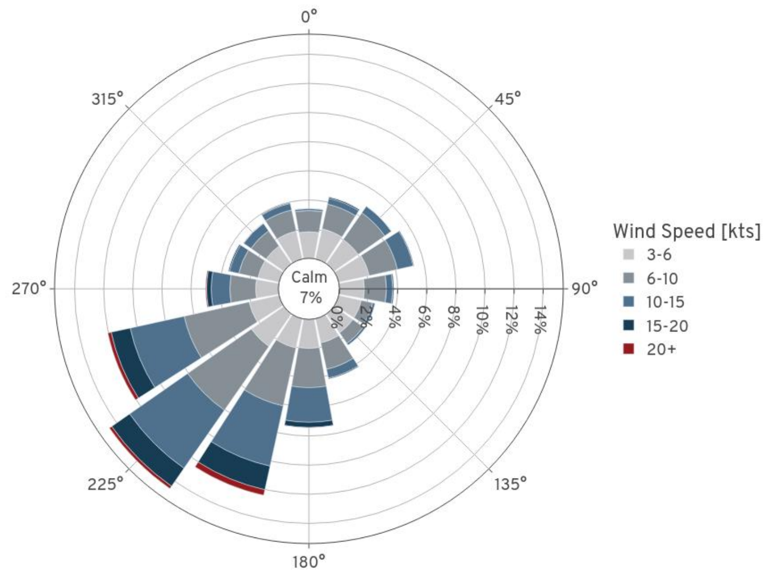

Figure 21: Wind rose day and night, full-year Brussels

The dominant wind direction is Southwest. 7% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 6 and 15 knots. This information is useful for the orientation of the vertiport or approach & departure trajectories of eVTOL.

Budapest

For the city of Budapest, around 68% of the operational conditions are classified nominal (see Figure 22).

In total, 10,7% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Budapest ranks number 375.

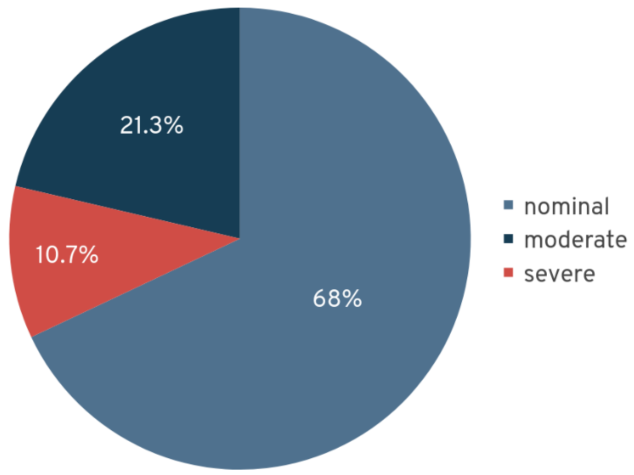

Figure 22: Overall Availability of Budapest

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a strong seasonal variation in terms of severe and nominal conditions. December is the month with the highest percentage of severe conditions and August is the one with the highest percentage of nominal conditions.

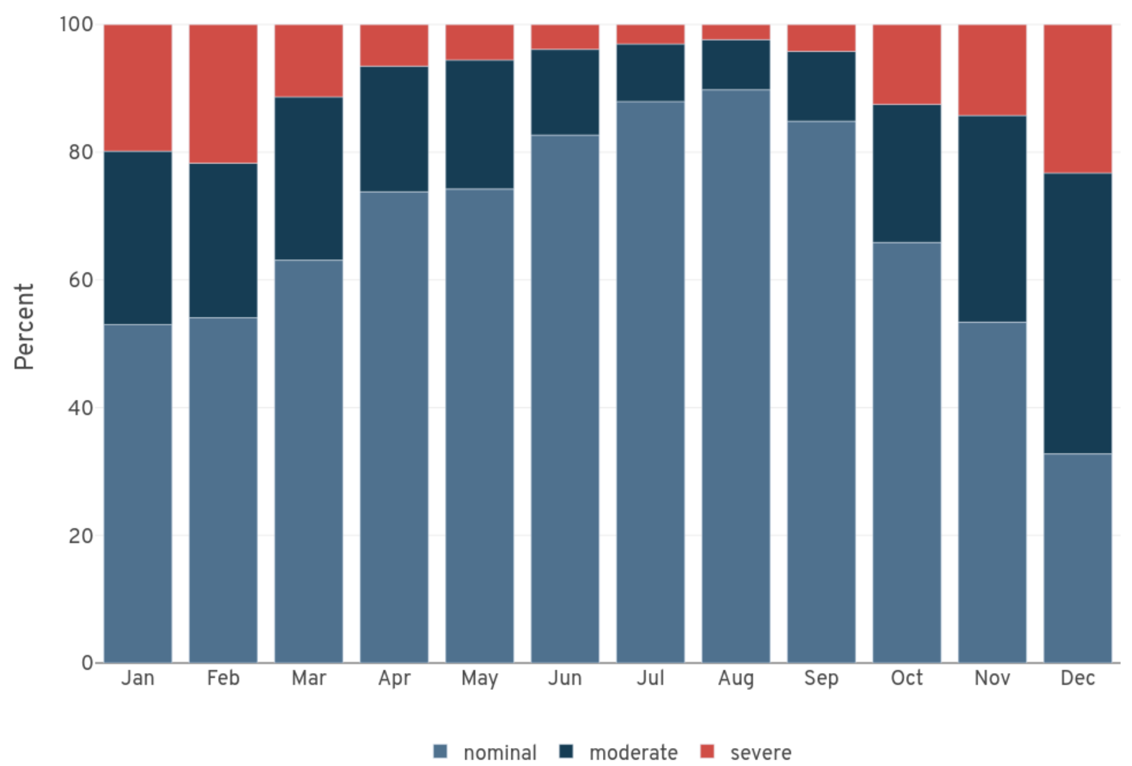

Figure 23: Seasonal dependency of operational conditions per month for Budapest

As shown in Figure 24 the predominant reason why weather conditions are classified as severe in Budapest is the weather parameter “gust factor” with 71%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on wind speed and wind gust limits of an aircraft, this may vary.

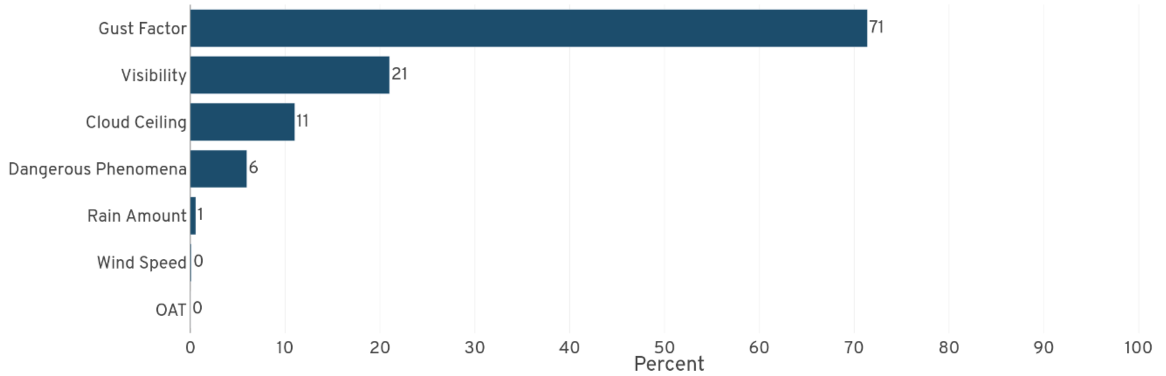

Figure 24: Main reasons for severe conditions, full-year for Budapest

The following analysis (Figure 25) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

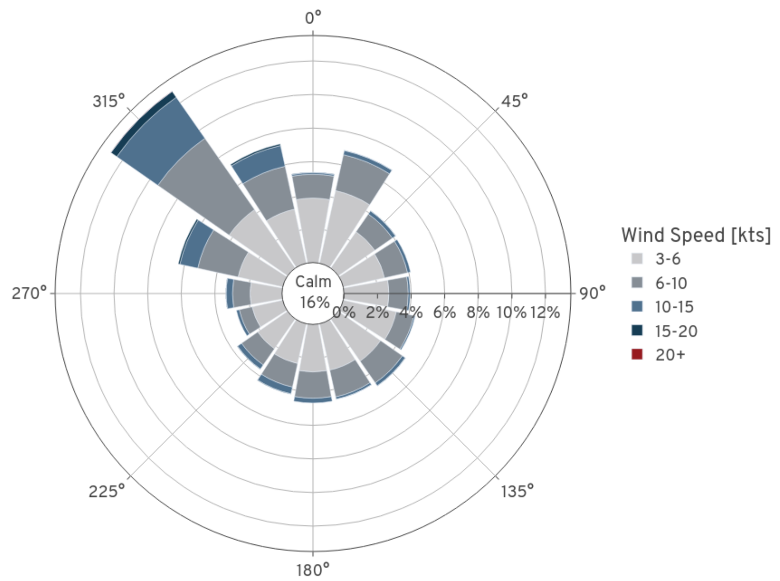

Figure 25: Wind rose day and night, full-year Budapest

The dominant wind direction is Northwest. 16% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 3 to 10 knots. This information is useful for the orientation of the vertiport or approach and departure trajectories of eVTOL.

Lisbon

For the city of Lisbon, around 70% of the operational conditions are classified nominal (see Figure 26).

In total, 7,9% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Lisbon ranks number 272.

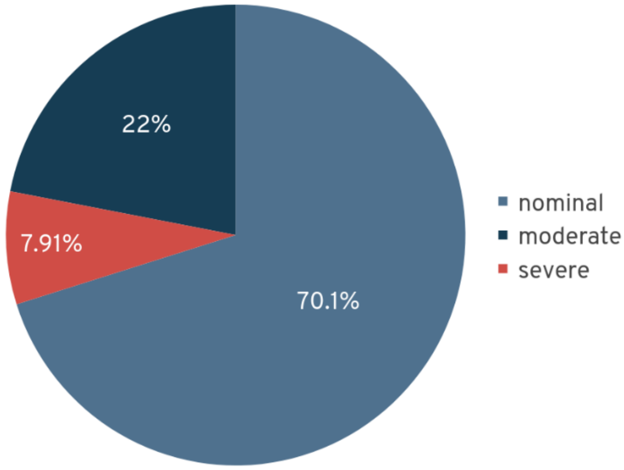

Figure 26: Overall Availability of Lisbon

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a moderate seasonal variation in terms of severe and nominal conditions. December is the month with the highest percentage of severe conditions and September is the one with the highest percentage of nominal conditions.

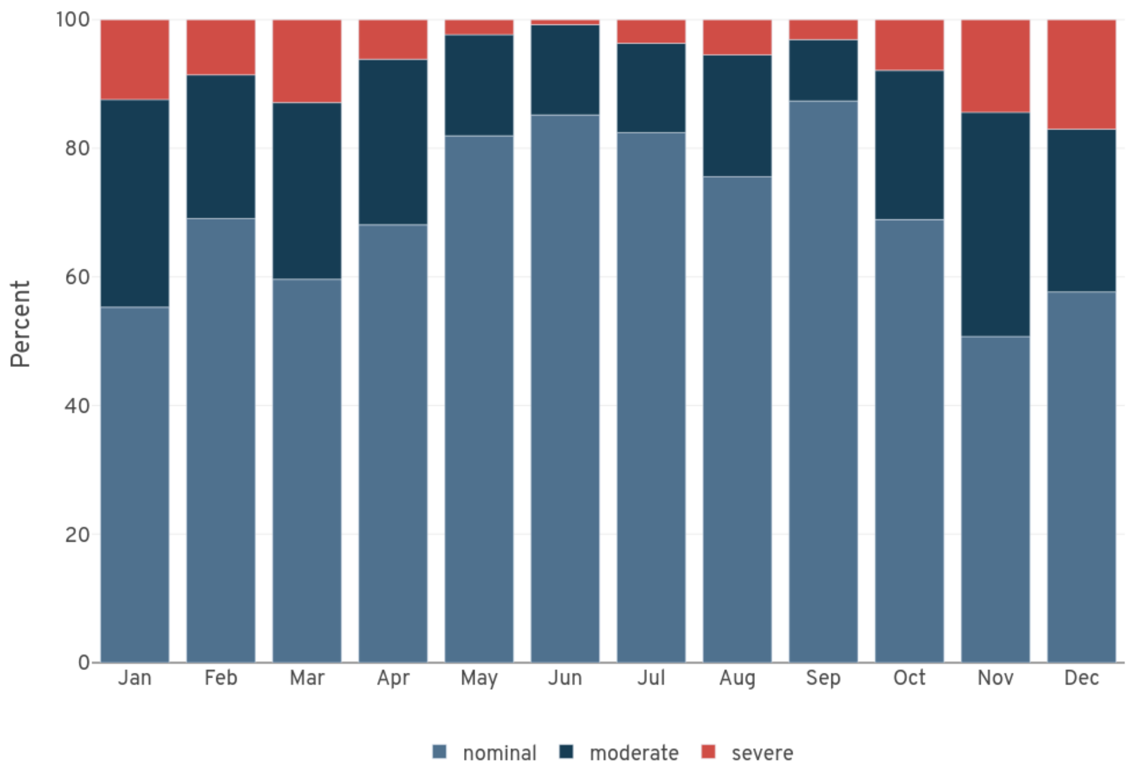

Figure 27: Seasonal dependency of operational conditions per month for Lisbon

As shown in Figure 28 the predominant reason why weather conditions are classified as severe in Lisbon is the weather parameter "gust factor" with 75%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on the wind speed and wind gust limits of an aircraft, this may vary.

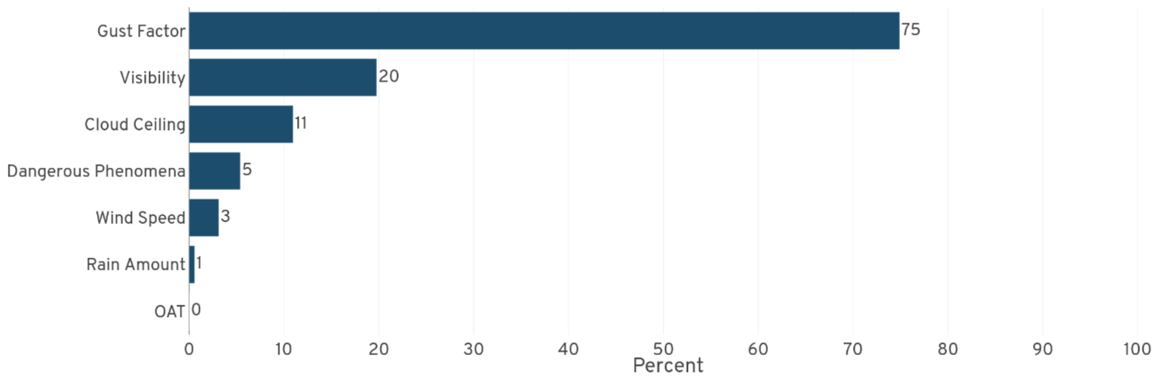

Figure 28: Main reasons for severe conditions, full-year for Lisbon

The following analysis (Figure 29) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

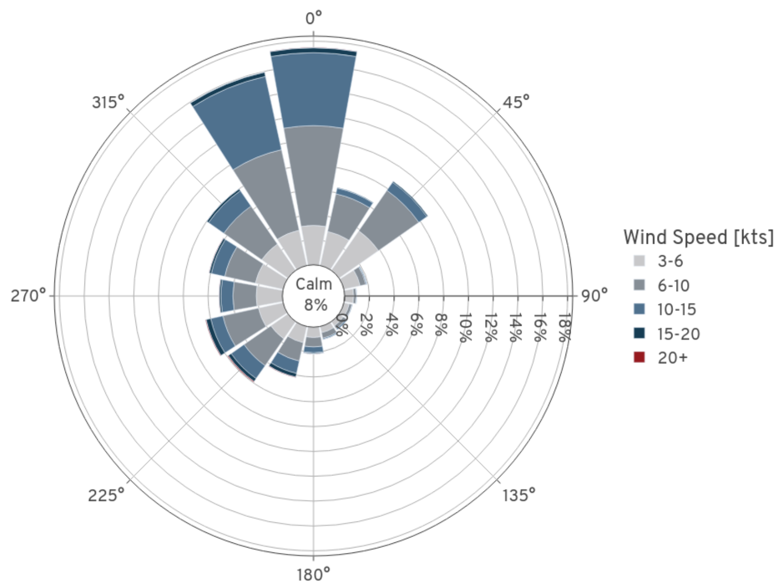

Figure 29: Wind rose day and night, full-year Lisbon

The dominant wind direction is North. 8% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 3 to 15 knots. This information is useful for the orientation of the vertiport or approach and departure trajectories of eVTOL.

London

For the city of London, around 50% of the operational conditions are classified nominal (see Figure 30). This is the lowest value of the 10 cities analyzed.

In total, 21,9% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, London ranks number 581.

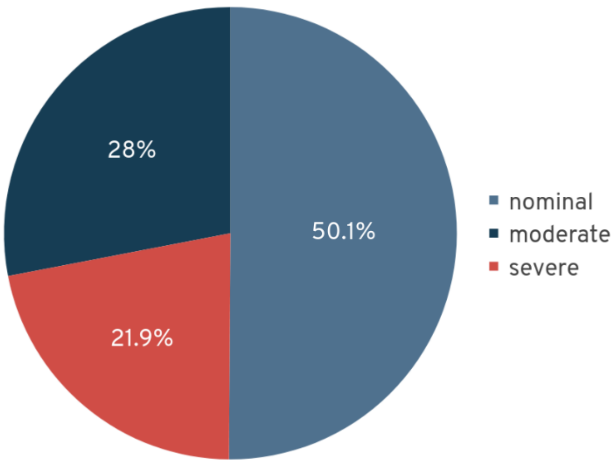

Figure 30: Overall Availability of London

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a strong seasonal variation in terms of severe and nominal conditions. February is the month with the highest percentage of severe conditions and May is the one with the highest percentage of nominal conditions.

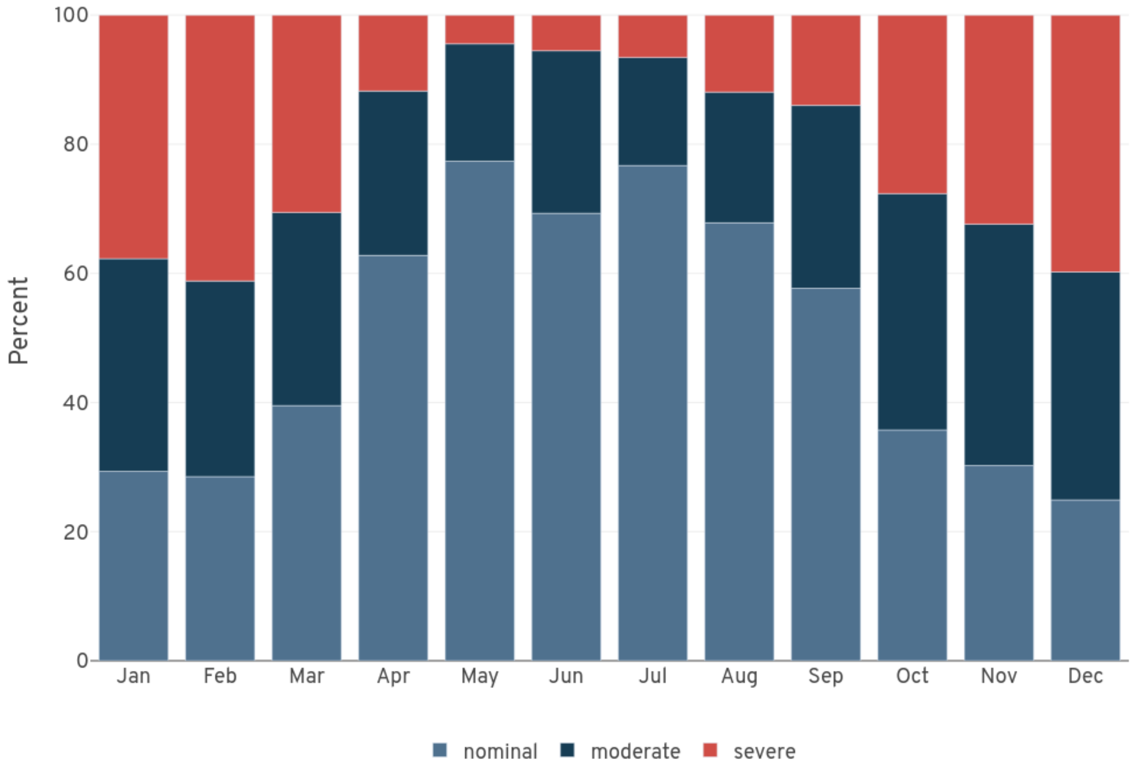

Figure 31: Seasonal dependency of operational conditions per month for London

As shown in Figure 32, the predominant reason why weather conditions are classified as severe in London is the weather parameter "gust factor" with 91%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on the wind speed and wind gust limits of an aircraft, this may vary.

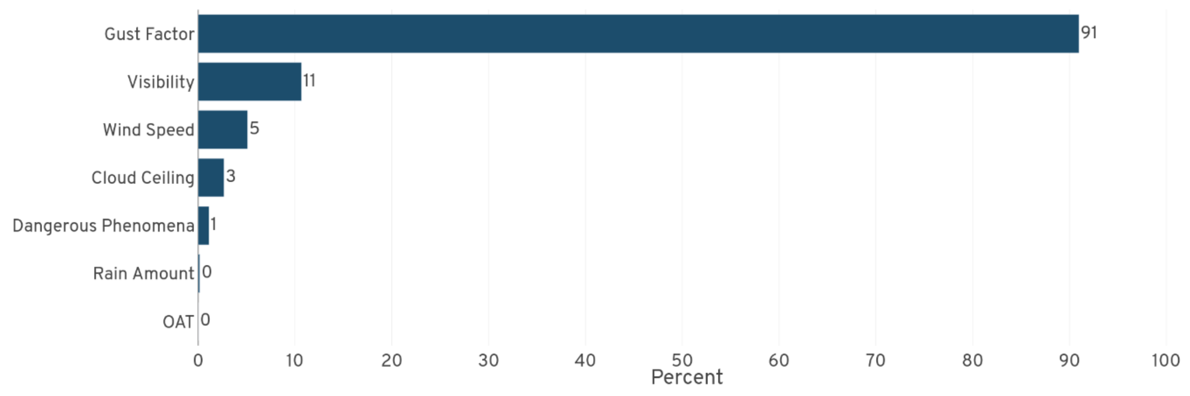

Figure 32: Main reasons for severe conditions, full-year for London

The following analysis (Figure 33) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

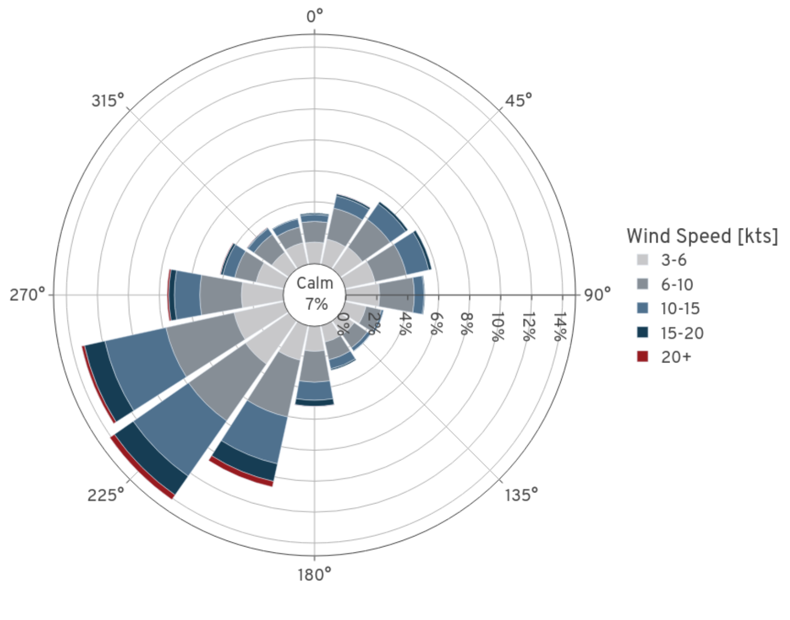

Figure 33: Wind rose day and night, full-year London

The dominant wind direction is Southwest. 7% of the time wind conditions were below 3 knots and calm. Whereas the majority of the winds are between 6 to 15 knots. This information is useful for the orientation of the vertiport or approach & departure trajectories of eVTOL.

Madrid

For the city of Madrid, around 75% of the operational conditions are classified nominal (see Figure 34).

In total, 6,6% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Madrid ranks number 158.

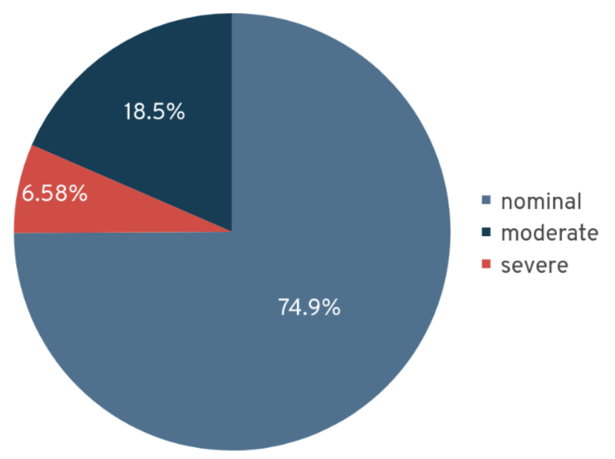

Figure 34: Overall Availability of Madrid

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a moderate seasonal variation in terms of severe and nominal conditions. December is the month with the highest percentage of severe conditions and July is the one with the highest percentage of nominal conditions.

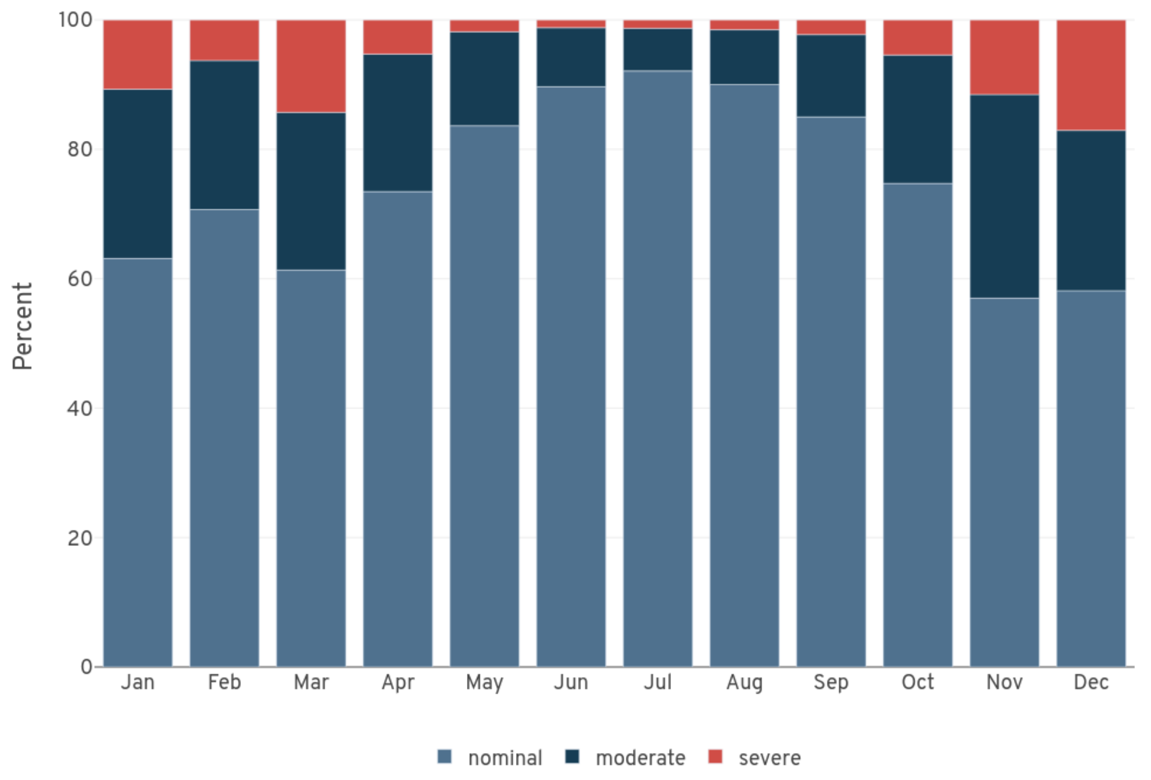

Figure 35: Seasonal dependency of operational conditions per month for Madrid

As shown in Figure 36, the predominant reason why weather conditions are classified as severe in Madrid is the weather parameter “gust factor” with 77%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on the wind speed and wind gust limits of an aircraft, this may vary.

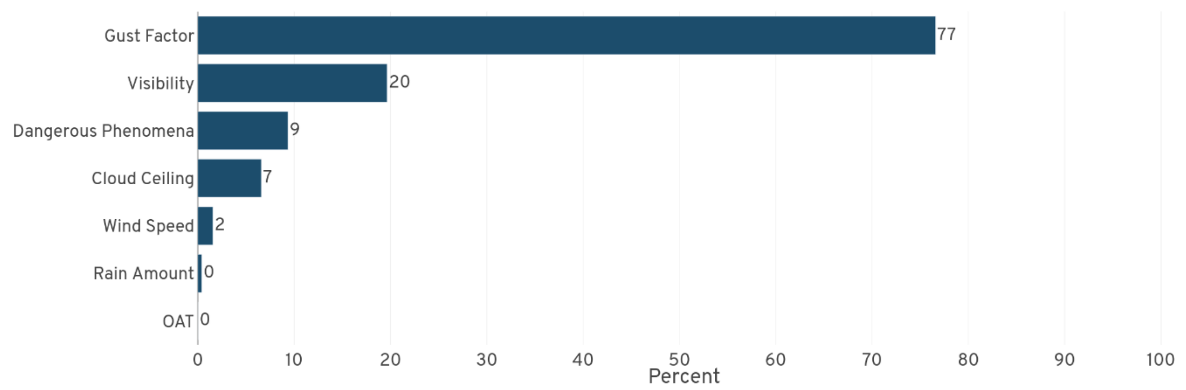

Figure 36: Main reasons for severe conditions, full-year for Madrid

The following analysis (Figure 37) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

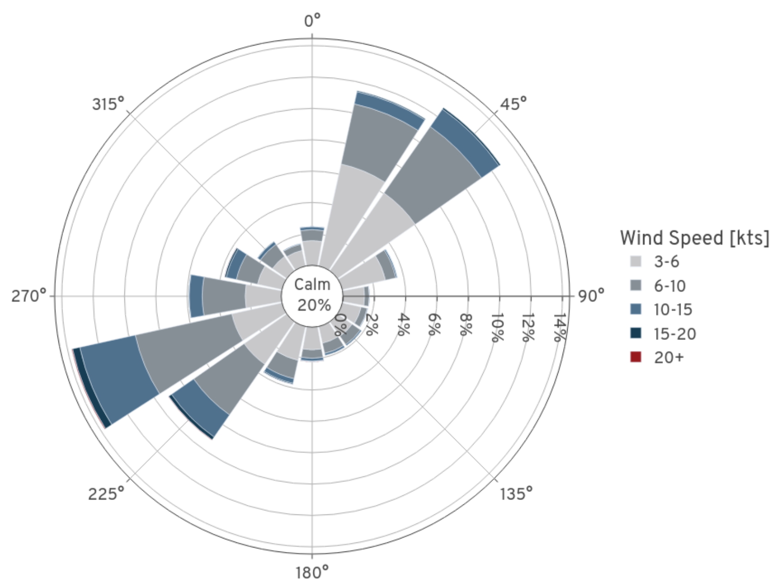

Figure 37: Wind rose day and night, full-year Madrid

The dominant wind direction is Northeast/ Southwest. 20% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 3 to 15 knots. This can be used for orientation of the vertiport or approach & departure trajectories of eVTOL.

Paris

For the city of Paris, around 62% of the operational conditions are classified nominal (see Figure 38).

In total, 15,7% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Paris ranks number 408.

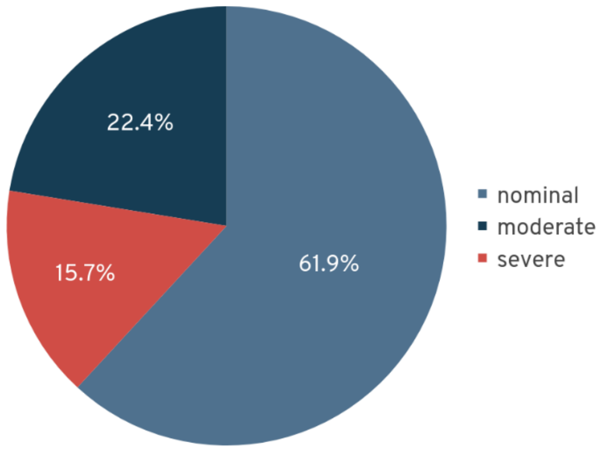

Figure 38: Overall Availability of Paris

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a strong seasonal variation in terms of severe and nominal conditions. December is the month with the highest percentage of severe conditions and July is the one with the highest percentage of nominal conditions.

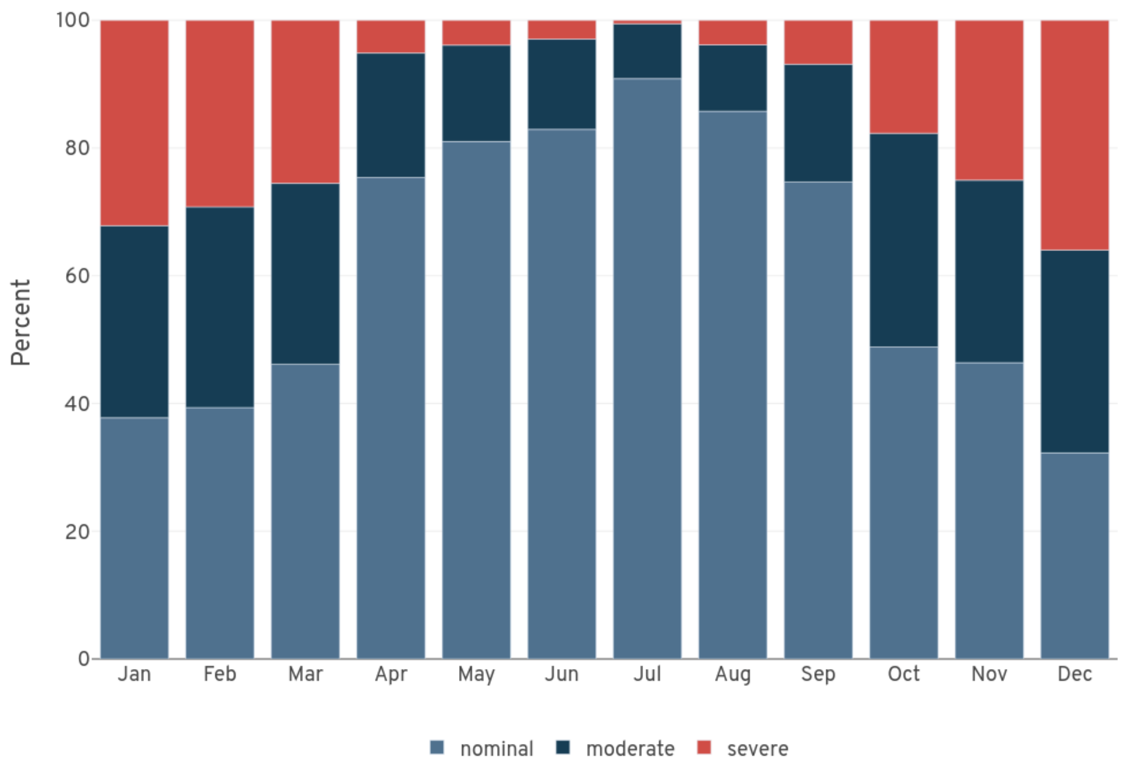

Figure 39: Seasonal dependency of operational conditions per month for Paris

As shown in Figure 40, the predominant reason why weather conditions are classified as severe in Paris is the weather parameter “gust factor” with 88%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on the wind speed and wind gust limits of an aircraft, this may vary.

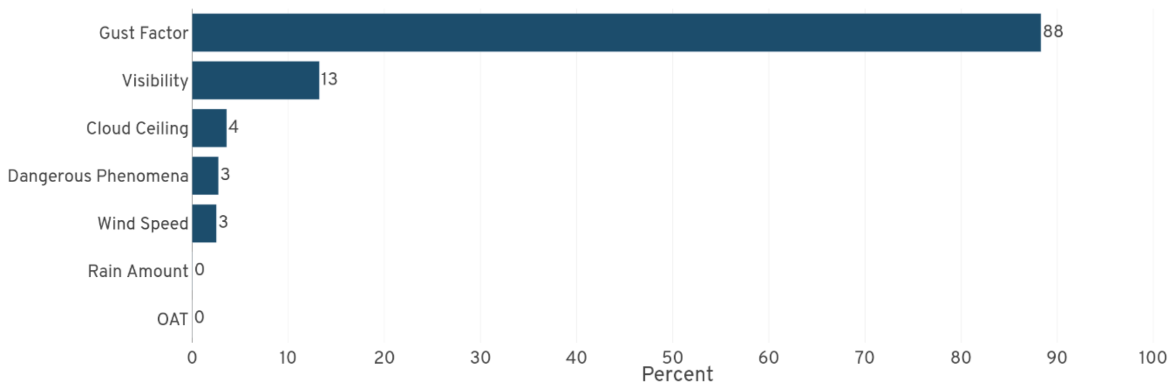

Figure 40: Main reasons for severe conditions, full-year for Paris

The following analysis (Figure 41) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

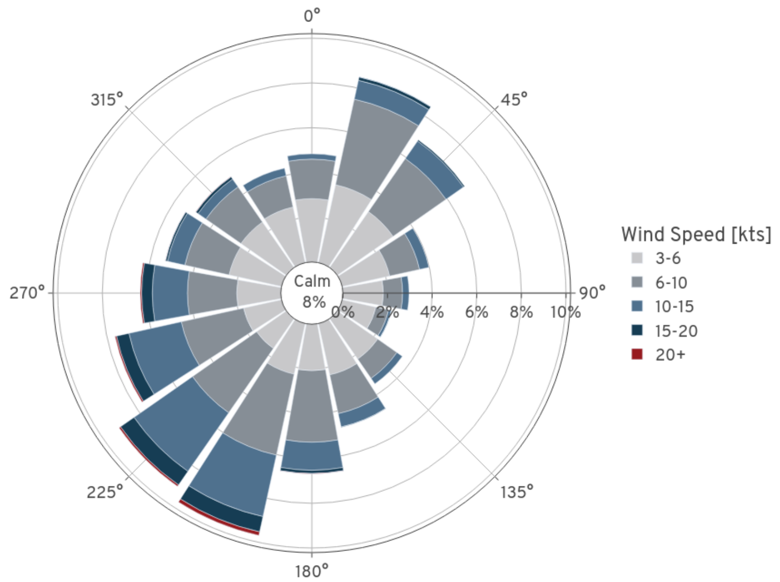

Figure 41: Wind rose day and night, full-year Paris

The dominant wind direction is Northeast/ Southwest. 8% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 3 to 15 knots. This is useful for orientation of the vertiport or approach & departure trajectories of eVTOL.

Rome

For the city of Rome, around 84% of operational conditions are classified nominal (see Figure 42).

In total, 5,3% of the time the operational conditions are classified as severe. Out of the 754 cities analyzed in Europe, Rome ranks number 73.

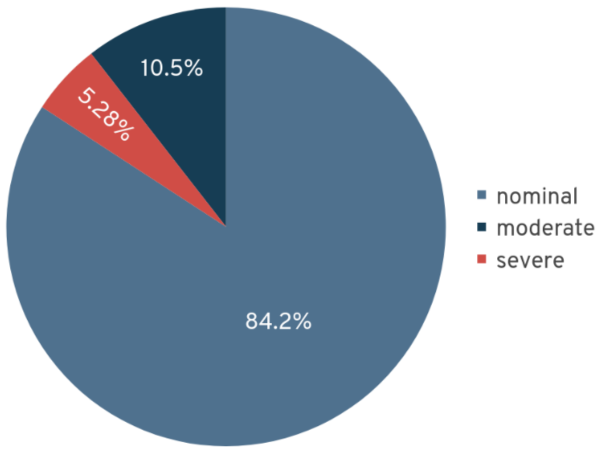

Figure 42: Overall Availability of Rome

Monthly operational conditions

The bar chart below shows the operational conditions per month. It reveals a smooth seasonal variation in terms of severe and nominal conditions. November is the month with the highest percentage of severe conditions and July is the one with the highest percentage of nominal conditions.

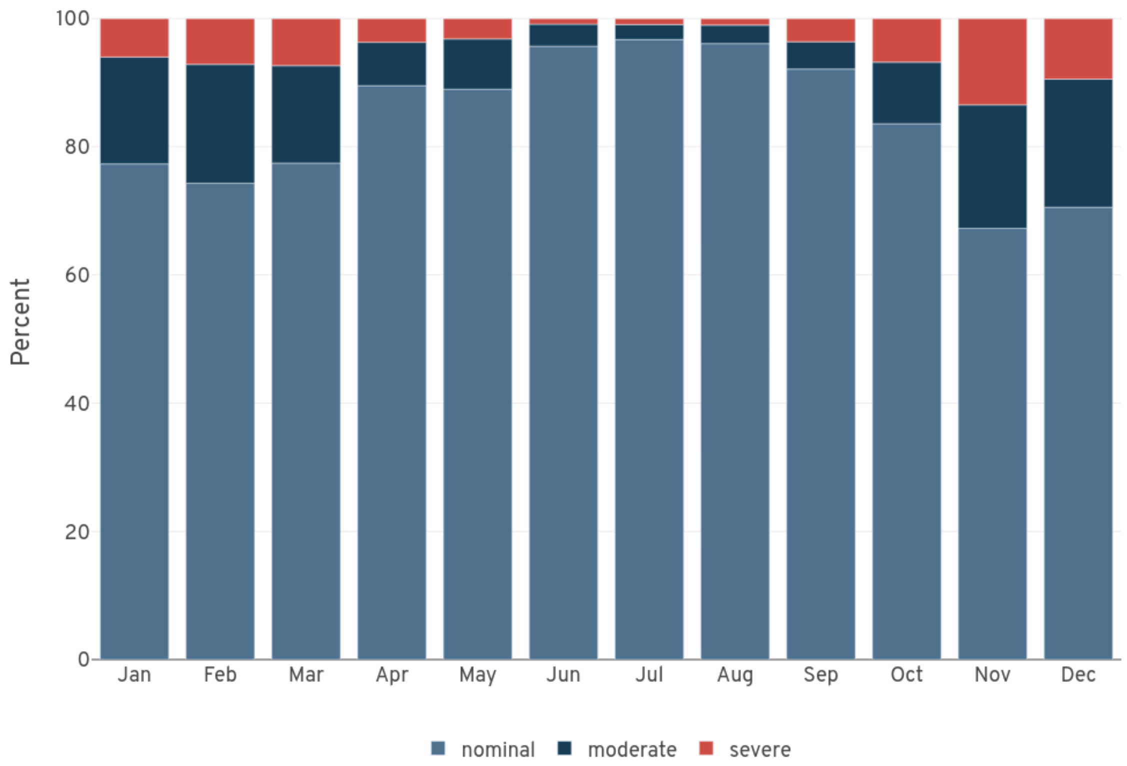

Figure 43: Seasonal dependency of operational conditions per month for Rome

As shown in Figure 44, the predominant reason why weather conditions are classified as severe in Rome is the weather parameter "gust factor" with 69%. The gust factor is defined as the difference between the peak wind gust of a 1-hour interval and the mean wind speed in the same period. Depending on the wind speed and wind gust limits of an aircraft, this may vary.

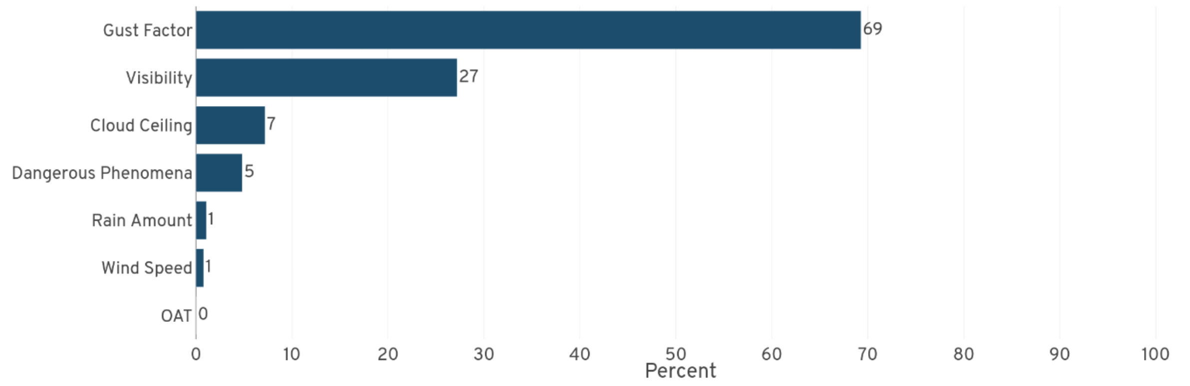

Figure 44: Main reasons for severe conditions, full-year for Rome

The following analysis (Figure 45) is a wind rose that shows the distribution of the wind direction and the wind intensity that did occur in the last 3 years. Furthermore, for each direction, the observed wind intensity is divided into 5 classes and their percentile of occurrence.

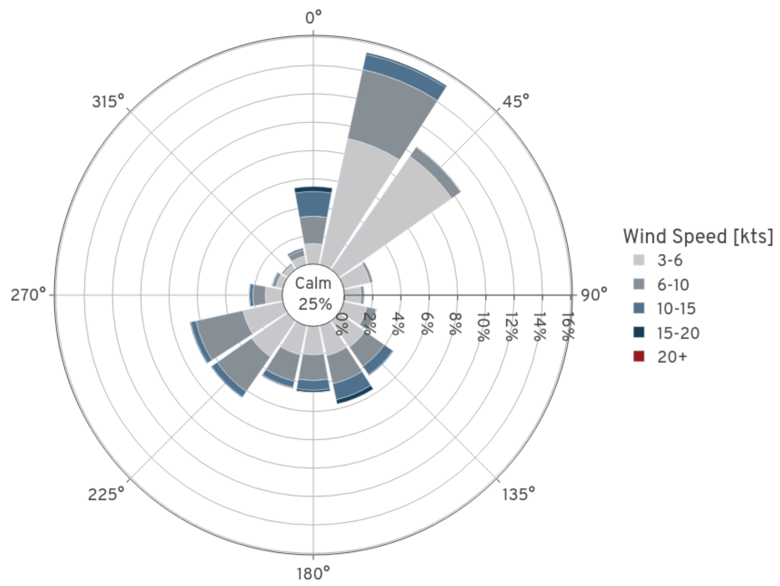

Figure 45: Wind rose day and night, full-year Paris

The dominant wind direction is Northeast. 25% of the time wind conditions are below 3 knots and calm. Whereas the majority of the winds are between 3 to 10 knots. This information is useful for the orientation of the vertiport or the approach & departure trajectories of eVTOL.

5. Summary

The analysis presented in this Whitepaper shows that there are strong differences in the prevailing weather conditions among the 10 largest european cities. For some cities, a high service availability can be expected throughout the year (e.g., Rome or Madrid), whereas other cities show strong seasonal differences (e.g., London or Berlin). This insight should be an integral part of the decision-making process before setting up a Vertiport and the flight operations.

Results of the analysis can vary depending on the aircraft limits that are selected. The study also reveals that the parameter *Gust Factor* is the driving parameter throughout all the cities assessed. It is followed by *Visibility* in cities giving rather calm conditions such as Athens. Being aware of the very loose constraints set for *OAT* and *Rain Amount* this could certainly change with a specification of an eVTOL.

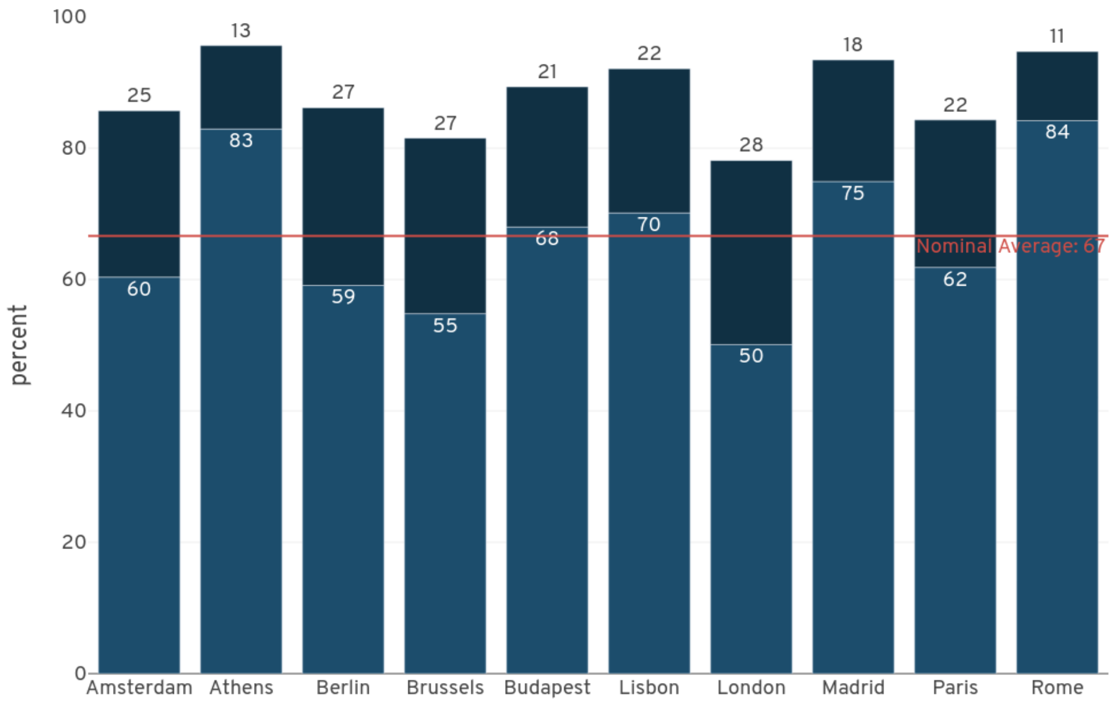

Figure 46: Comparison service availability between 10 cities (covering nominal & modearate conditions)

The analysis approach is kept generic allowing a tailored approach fro concrete eVTOL designs and their limitations. One idea to sharpen the study is to reduce the share of the days classified as *moderate* to carve out a better understanding of the actual service availability (nominal = good to fly | severe = no flights).

This would provide a better understanding of the actual service availability a company can plan with. However, therefore concrete information from eVTOL manufacturers and operators is required in order to be able to make accurate statements.

Going into Detail

The Whitepaper focuses on a high-level analysis of the service availability and the comparison of the 10 cities. For concrete decisions, e.g., for the placement of a vertiport, more detailed analyses are required, that either show differences between day and night or use a higher vertical resolution to understand certain weather effects like local wind effects such as low level jets.

Figure 47 provides an example of such an analysis. The figure shows the conditions that are classified as Nominal, distinguished by day and night. For example, in April 78% of the daylight hours are nominal, however, only 51% of the night hours are flyable. Thus, the overall yearly conditions could be better in comparison to other cities when only taking nominal daytime hours into account. Eventually, it makes always sense to consider various aspects in the location analysis for obtaining a most detailed picture of the operational condition. Furthermore, some cities show stronger differences in the absolute daytime in summer and winter whereas, in other geographical areas, there are fewer or no seasonal differences. This will also impact the overall service availability, highlighted by the lines that show the absolute time of nominal conditions (Figure 47).

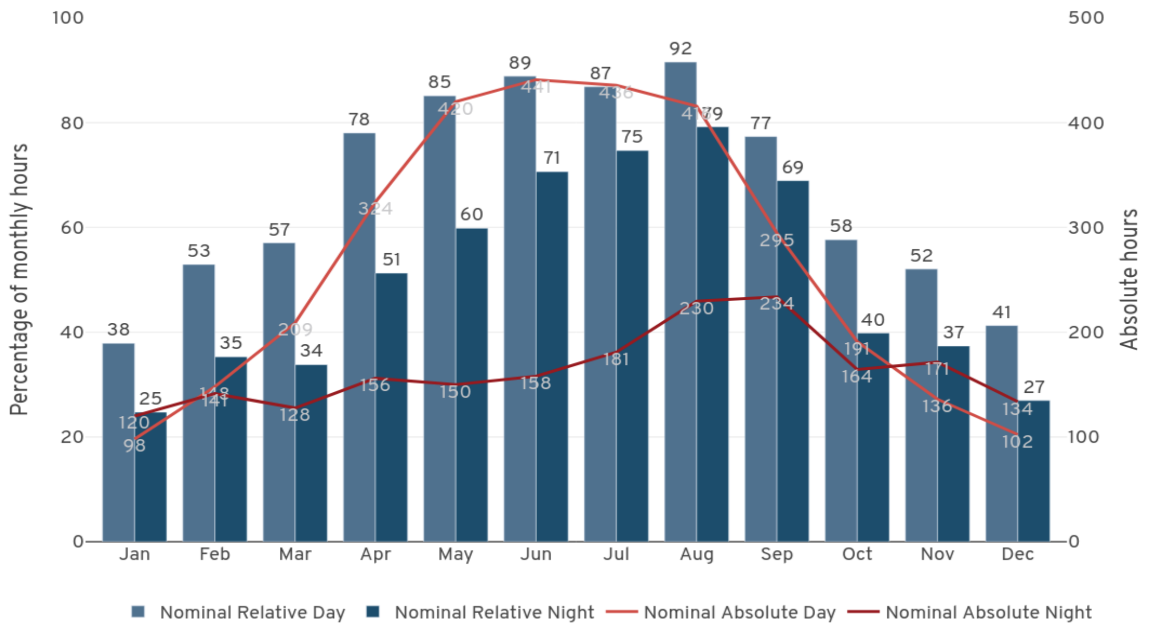

Figure 47: Influence of day and nighttime on nominal conditions for Berlin

Limitations of the Analysis

This Whitepaper outlines opportunities of using historic weather data in combination with operational limitations of eVTOL to quantify operational availability. It is held generic by intention and can be quickly adjusted to the needs of stakeholders in the UAM eco-system.

We are aware that this first whitepaper can be further developed and in its current version has some limitations, which are as follows.

- In this study typical performance and limitation characteristics of multirotor eVTOL (e.g., Volocopter or EHANG) were considered. Self-explaining that the range of some parameters would change if a lift & cruise concept (e.g. Wisk or Joby) with potentially more sensitivity to a cross-wind component would be investigated.
- The analysis is limited to locations on the ground and does not reflect conditions in the approach and departure path of an eVTOL. That for example could be nocturnal low-level jets (LLJ) with wind speeds up to 45kts. Such phenomena are not considered in the study but are assessable when doing local analysis considering weather conditions at altitudes.
- Furthermore, the study does not explicitly differential between visual/instrument meteorological conditions (VMC/IMC) whereas most eVTOL operations are planned according to Visual Flight Rules (VFR). For such kinds of analyses, further information on visibility, cloud base, ceiling, and coverage should be considered.
- Flight in icing conditions is another aspect to be considered in further studies since most eVTOL concepts plan their initial aircraft without anti-icing systems.

6. Outlook

Based on the feedback we receive on this white paper, it is planned to extend the scope of the analysis to more cities around to globe. The aim is to generate a global report on the "UAM Service Availability" during the coming months. Furthermore, we like to even widen the scope and assess the impact of the eVTOL design and configuration on its operational capabilities and effects on the service availability on route networks in different locations.

Incorporating different eVTOL Types

Generally, there are different concepts of eVTOL (electric vertical take-off and landing). Due to the different designs, they come in hand with different aircraft performance characteristics. The general concepts are illustrated in Figure 48 below. The distribution of more than 200 eVTOL concepts according to a study of Porsche Consulting [2] is as follows:

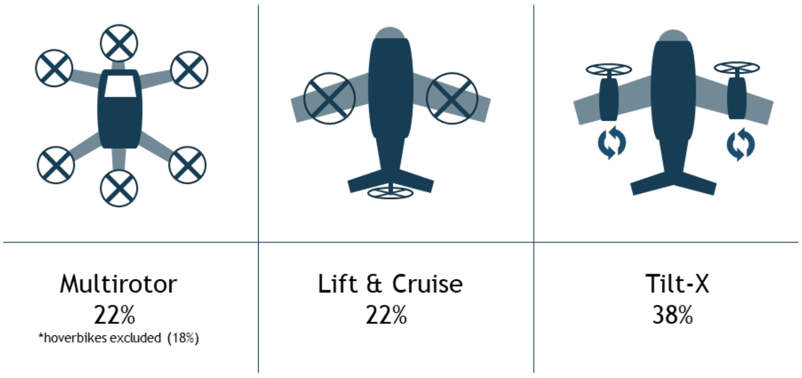

Figure 48: Distribution of eVTOL concepts according to Porsche Consulting [2], (hoverbikes removed)

For reasons of simplicity, the analysis used one aircraft configuration only (see Table 3). However, there is the possibility to select specific parameters and operational limitations that can be considered in future analysis for any other type.

Aircraft Performance & Equipment			
eVTOL Multirotor 	Performance	Range (nominal flight time)	20 km (15 min)
		Cruise speed	40 kn (EAS)
		Cruise altitude	1000-1500ft
	Equipment	Flight Category	VFR / VMC
		De-icing system	No
		Swappable batteries	Yes

Table 3: Generalized aircraft performance characteristics of a multirotor concept

Having the possibility to benchmark different eVTOL types will allow future eVTOL airline operators to support their buying decision and make the best use of what is already available. How this could be done is further discussed in the next chapter.

Route Networks and Vertiport Placement

For future analysis, the focus could be extended to route networks to better understand the weather impact enroute. Therefore, our Digital Twin Technology can be used to create a data basis for this more sophisticated assessment. It will provide insights into average distances that can be flown with respective weather conditions and how these distances differ for certain geographical areas and seasons. In the concept of Figure 49 routes are simulated in all directions of a given point and eVTOL performance (e.g. battery endurance). Applying route trajectory analysis the areas which can be serviced throughout the year with a certain confidence, e.g. 99% or 95% can be visualized for a better understanding of a future flight operation.

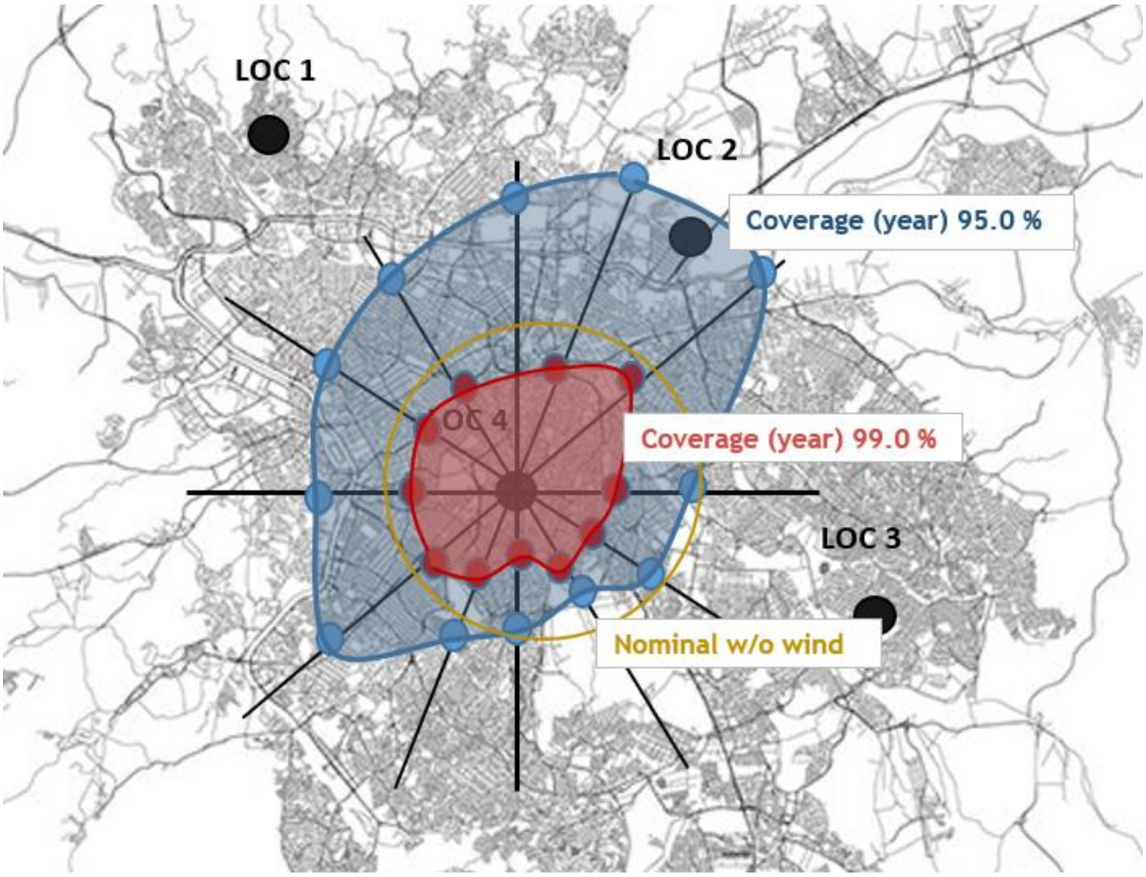

Figure 49: Route network coverage analysis to design initial operations of eVTOL

7. Appendix

Coordinates that were used for 10 cities

Name City	Name Railway Station	Latitude	Longitude
Amsterdam	Amsterdam Centraal Station	52.3791° N	4.9003° E
Athens	Athens Railway Station	37.9923° N	23.7208° E
Berlin	Berlin Hauptbahnhof	52.5251° N	13.3694° E
Brussels	Brussels-Midi	50.8361° N	4.3355° E
Budapest	Budapest-Keleti Railway Station	47.5004° N	19.0840° E
Lisbon	Rossio Railway Station	38.7144° N	9.1409° W
London	Paddington Railway Station	51.5167° N	0.1769° W
Madrid	Estación de Atocha	40.4050° N	3.6883° W
Paris	Gare du Nord	48.8809°N	2.3553°E
Rome	Roma Termini	41.9013° N	12.5016° E

Table 4: Overview of analyzed locations

8. References

[1] Population data by NGIA, US Geological Survey, US Census Bureau, and NASA, 2021

[2] The Economics of Vertical Mobility - A guide for investors, players, and lawmakers to succeed in urban air mobility; Porsche Consulting, 2021

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We hope you enjoyed reading this Whitepaper.

Please let us be part of your thoughts and send your feedback to

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