ROADMAP

Electric flight in the Kingdom of the Netherlands

Client Ministerie van Infrastructuur en Waterstaat
Status Final/P01.01
Date: 22 december 2021

HASKONINGDHV NEDERLAND B.V.

Schenkkade 49
2595 AR DEN HAAG
Netherlands
Maritime & Aviation
Trade register number: 56515154

+31 88 348 13 00 **T**
+31 70 381 55 82 **F**
info@naco.rhdhv.com **E**
royalhaskoningdhv.com/naco **W**

Document title: Roadmap – Electric flight in the Kingdom of the Netherlands

Reference: BH6370MARP2105192005
Status: P01.01/Concept
Datum: 22nd of December 2021
Project name: n.a.
Project number: BH6370
Author(s): Marlies Hak, Christine Driessen

Classificatie
Project related

Table of content

1 Introduction

In 2020, the Netherlands has set ambitions for sustainable aviation, as part of the Luchtvaartnota [1]. The ambition is to reduce CO2 emissions by, amongst others, have zero-emission ground operations and electric taxiing introduced by 2030. By 2050, all short-distance commercial flights departing from the Netherlands should be full-electric.

Electrification of aviation is one of the routes to a more sustainable air transport. Nevertheless, aviation is a modality where sustainability is still immature. This is partly due to the requirements for safety and technological challenges. Innovations that aim to reduce the climate impact of aviation, such as the electrification of aviation, therefore take time.

The last decade, technological advancements in several fields such as batteries and materials made the development of electric transport possible. However, batteries are still very heavy. Therefore, the development started, amongst others, in the automobile industry where minimising weight is less of a concern. Many research activities are being undertaken that strive to obtain greater battery specific energies, which increases both vehicle range and load capacity. For this reason, electric aircraft developments are still focused mainly on small aircraft with a short range and lower passenger capacity.

For the coming five to ten years several companies have dedicated their efforts towards development of electric aircraft with greater passenger capacity and range, albeit fully or hybrid electric aircraft that are new or retrofitted.

Since the implementation of electric flying is getting closer, it becomes increasingly important to investigate what is required, in addition to the aircraft, to make electric aviation a feasible alternative to conventional aviation. The implementation is expected to have an impact on airlines, airports, energy infrastructure, which will have to be supported by changes in legislation and regulations.

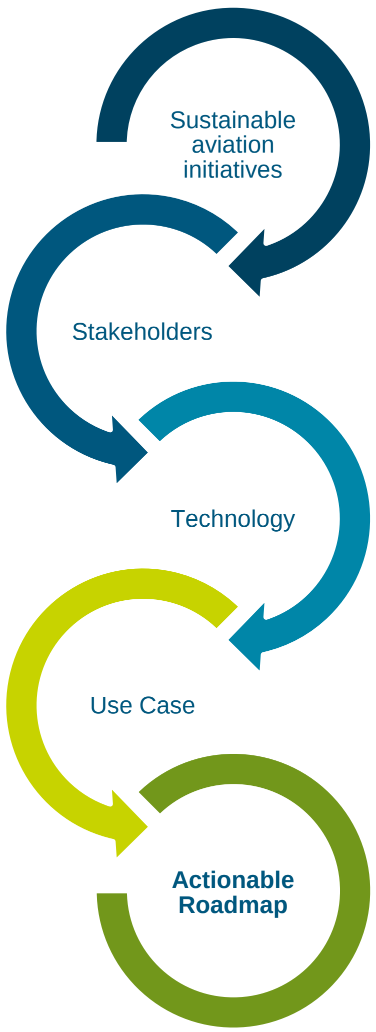
Learning and innovating is essential for the implementation of electric flight. Within the Kingdom of the Netherlands, the infrastructure is further developed in the Netherlands than on the Caribbean islands. Therefore, the implementation of electric flight is likely to be easier in the Netherlands than on the islands. Nevertheless, the feasible range and passenger numbers of electric aircraft by 2030 create opportunities for regional mobility services with 9- and 19-seaters. These electric aircraft will be very suitable for the inter-island flights at the ABC islands. Moreover, reliable and affordable air connectivity is vital to the local communities of the islands. It could be said that the ABC use case is a great opportunity to start implementing electric flight.

To get more insight into the steps that need to be taken, the Ministry of Infrastructure and Water appointed NACO and NLR to prepare a roadmap, focusing on the implementation of electric flight in the Kingdom of the Netherlands. In this roadmap a step-by-step action plan is being developed for the stakeholders in the Kingdom of the Netherlands. A use case is prepared for the aviation ecosystem of the ABC islands, as a practical example of the impact the implementation of electric aircraft will have. The study provides a quantification of the impact of the implementation in terms of (new) infrastructure, energy demand and costs.

The aim of this study is to give insight into the steps and actions that are needed to make a transition to electric flying within the Kingdom of the Netherlands. The case acts as a starting point and stimulus for the ABC islands to be connected in a sustainable, reliable, safe and affordable way.

2 Report structure

This report is structured as followed.



In chapter 3 an overview is given of sustainable aviation in Kingdom of the Netherlands.

Subsequently, in chapter 4 the aviation stakeholder ecosystem is described. This analysis is supported by stakeholder interviews and includes:

- Stakeholder identification,
- Stakeholder analysis exploring the roles and dependencies.

In chapter 5, an overview is given of the developments in electric aircraft technology, charging infrastructure and energy supply. This is supported by interviews with experts.

Chapter 6,7 and 8 comprise the use case. The case is built up by:

- An introduction of the ABC islands,
- An assessment of the potential replacement of the existing aircraft flying between the islands by electric aircraft,
- An implementation plan, which introduces electric flight in three phases,
- A list of defined assumptions for the quantification of the impact study,
- An impact analysis on (sustainable) energy requirements, ground infrastructure, and costs.

In chapter 9, the study concludes with a concise roadmap towards 2035.
Finally, recommendations for next steps after this study are given in chapter 10

3 Sustainable aviation in the Kingdom of the Netherlands

3.1 Policies

Today two major documents provide policy and guidance regarding the future ambitions of hybrid-electric aviation in the Netherlands.

Luchtvaartnota

The Dutch government has launched its Luchtvaartnota 2050 last year in 2020. This policy document envisions the long-term path for the aviation sector in the Netherlands. The most important pillars of the Luchtvaartnota are safe, connected, liveable and sustainable aviation.

Hybrid-electric aviation is one of the technology tracks that the government sees as paving the way to a safe, more silent and cleaner aviation.

Concrete goals that have been set with regards to (hybrid-)electric aviation for 2030 are [1]:

- Electric taxiing is normative,
- Living Lab for innovations in aviation,
- The first hybrid-electric aircraft up to 50 passengers are in use.

For the longer term, 2050 the goal is that all short distance flights (up to 500 km) departing in the Netherlands are fully electric.

Actieprogramma Hybride Elektrisch Vliegen (AHEV)

The roundtable “Duurzame Luchtvaarttafel” (Sustainable Aviation roundtable) delivered the Concept Agreement Sustainable Aviation in 2019. Within this Agreement several working groups are active, one focusing on hybrid electric flight. This group has its own action programme, called “Actieprogramma Hybride Elektrisch Vliegen” (AHEV), which is a result of a collaboration between government, businesses and knowledge and research institutes. This programme provides a pathway on how The Netherlands can develop itself on hybrid electric aviation for the commercial aviation acting as one of the international frontrunners on hybrid electric aviation [2].

The programme sets ambitions for commercial aviation, General Aviation and the ground operations, with the ultimate goal to have emission free aviation in 2070. On the shorter term, a reduction of 15% domestic flight emissions with respect to the 1990 level, with the end goal that all domestic flight is emission-free in 2050 [2].

3.2 Sustainable aviation initiatives and collaborations

Today several initiatives take place on the subject of electric aviation and sustainable aviation, some examples of collaborations in the Netherlands are given below:

- **DEAC - Dutch Electric Aviation Centre**
  DEAC is a centre which investigates how small aviation can fly more sustainably in the future. Their goal is to make aviation cleaner, quieter and more affordable and they want to make electric aviation more accessible by conducting research and experiments with aircraft, infrastructure and regulations that can support its implementation. They work together on the topic of electric flying in the Netherlands with business communities, educational institutes/schools and the government [3].

- **Power Up**
  Eindhoven Airport, Rotterdam The Hague Airport, Groningen Airport Eelde and Maastricht Aachen Airport are going to carry out tests with electric flying. In the shared learning environment 'Power Up', the aim is for the airports to gain knowledge of the feasibility, potential and handling of electric flights. The initiative Power Up was started as a feasibility study to understand the implication of electric flying and to estimate whether it is economically interesting. Their test results will be used for research into the operation of scheduled flights with aircraft powered by electricity, to connect regions and create a dense network within Europe. They expect that the first electric passenger flights will be operated between airports in the Netherlands within five years. They aim to have the first commercial electric flight in the Netherlands as a learning goal by 2026.

- **Stichting Duurzaam vliegen**
  In 2018, "Stichting Duurzaam Vliegen" was established as a representative party for General Aviation. Their ambition is to reduce greenhouse gas emissions by 15% by 2030 compared to 1990 and to be able to fly emission-free by 2050. [4]

- **E-Flight Academy**
  The very first electric flight school in the world, based at Teuge Airport. Their goal is to make flying more sustainable, by flying electric. E-Flight Academy operates two Pipistrel Velis Electro aircraft for their flight school. Besides flying electric they also try to reduce CO2 by teaching in simulators and digitalizing processes as much as possible.

In the Dutch Caribbean there are also several ongoing initiatives:

- **Bonaire Air Ambulance**
- Fundashon Mariadal are responsible for care on the islands. For optimal use, certain care is only available on one of the islands which makes reliable transport between them crucial. [5] To become independent from airlines, Air Ambulance would like to acquire their own fleet and they are investigating the feasibility of having electric or hybrid electric aircraft. There ambition can be a catalyst for new techniques to create a new eco-system.

- **Dutch Caribbean Cooperation of Airports (DCCA)**
  DCCA is an initiative of airports, established in 2021. Their objective is to improve the individual airports on several key elements, such as sustainability. One of their efforts is focused on improving connectivity between islands, aiming for a sustainable (electric), reliable and affordable public transport-like air connection [6].

The above-mentioned initiatives are great kick-starters of new movements in sustainable aviation. Despite these initiatives, on a larger scale collaboration is needed to encourage a system change in the air transport system. For this to happen, aviation stakeholders need to act now. In the following chapter the stakeholders, their roles and their dependencies will be analysed.

4 Stakeholder ecosystem

For a succesful implementation of electric aircraft into the aviation ecosystem, a system change is needed. To make sure this change can occur, it is necessary to have a good understanding of the stakeholders that play a major role in this ecosystem. In this chapter the aviation stakeholders are identified, including their roles and responsibilities, their dependencies and how they can emhance the implementation.

4.1 Stakeholder overview

The aviation ecosystem consists of eight major stakeholders (Figure 1), each having its function and specific role in the transition to electric flight.

Figure 1 - The major stakeholders in the aviation ecosystem (source: author)

The function and specific role in the transition to electric flight of each stakeholder is given in Table 1.

Table 1 - Overview of functions and specific role of the stakeholders in the transition to electric flight

Stakeholder	Function	Role in transition to electric flight
1. OEM and MRO	To develop airworthy aircraft and components. To execute specific repair, service or inspection of an aircraft. Maintenance to ensure the safety and airworthiness of an aircraft.	To develop electric aircraft, charging technology and components. To develop maintenance programs and parts for electric aircraft.
2. Aviation authority and association	To make safety rules, issue certification specifications, means of compliance and guidance material. Certify aircraft and components. To monitor and enforcing safety standards. To implement new requirements for operations and infrastructure.	To certify the new aircraft, adapt rules and regulations for aircraft, pilots and ANSP's.
3. ANSP	To provide the service of managing the aircraft in flight or on the manoeuvring area of an airport.	To adapt and integrate new routes for the electric aircraft.
4. Airlines	To offer air transport services for passengers and cargo. To lease/acquire and operate the new electric aircraft.	To re-invent suitable business models and acquire new electric aircraft.
5. Airport	To facilitate air transport of passengers and goods	To plan for and purchase new infrastructure to accommodate electric aircraft.
6. Energy supplier, network operator and energy provider	To produce electricity. To provide electricity to the airport. Ensuring the electricity network is sufficient for energy demand.	To produce electricity preferably in a renewable way to enable true zero-emission flight. To make sure the network is robust enough to cope with high energy demand
7. Educational institute	To train and educate air and ground personnel in the aviation sector. Supporting and collaborating with manufacturers in R&D activities.	To specifically train staff for electric aircraft operations, including MRO. Intensify R&D activities on electric flight and the challenges that are ahead of it.
8. Government	To make policies, laws and monitor compliance.	To monitor, enable and facilitate the transition to electric flight, e.g. by creating policies, measures that stimulate investing in electric aviation, including energy related challenges.

4.2 Stakeholder dependencies and actions

Collaboration between the stakeholders is very important as the implementation of electric aircraft involves a system change in which everyone needs to act. In the following overview the dependencies and possible actions to enhance the transition is given for each stakeholder. In Figure 2, the high-level relationships between the different stakeholders is visualized.

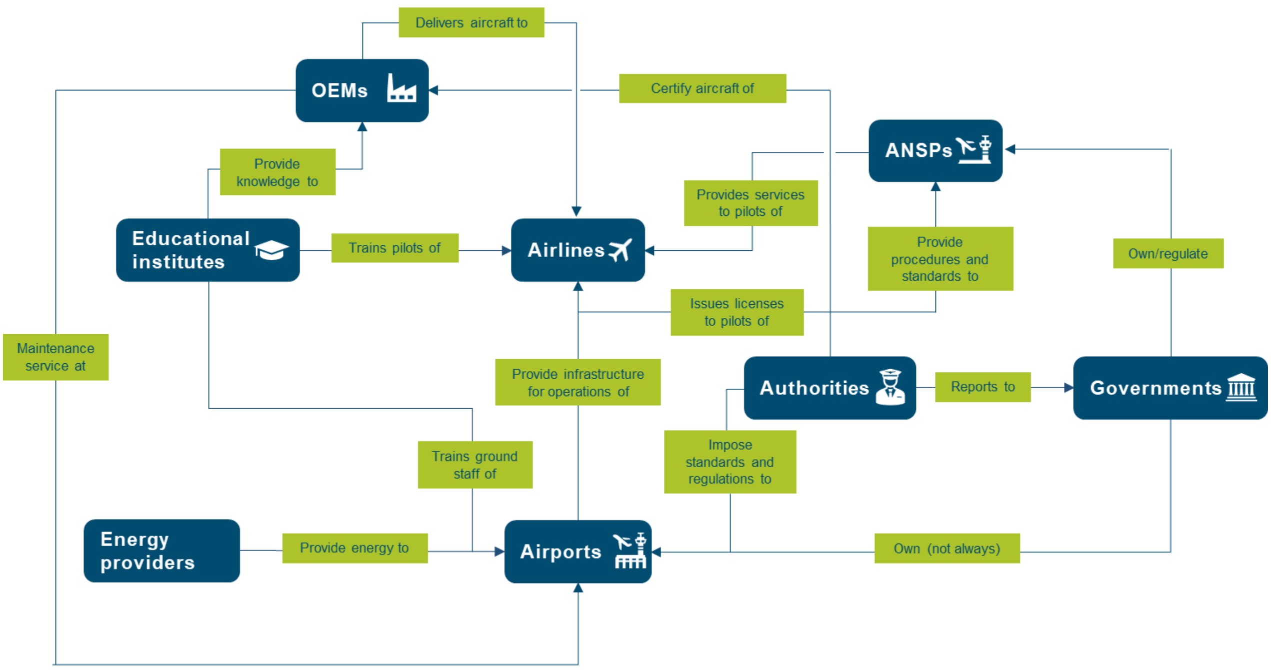


Figure 2 – High-level relationship diagram of aviation stakeholders (source: author)

OEM

As an OEM, developing an aircraft and its components is very time intensive and costly. Partly because the certification process by the authorities can take years. Since electric aircraft development involves new technologies onboard of an aircraft, new certification challenges are imposed. However, not all rules have been adapted yet, making it more time consuming for manufacturers to get their aircraft certified. Important to note that there is also interaction between the OEMs and certification agencies: new insights will be embedded over the years.

There is also a relationship with the infrastructure which is in place or has to be developed yet; airports should be able to accommodate the electric aircraft by installing proper charging facilities. Standardization also plays a role in here. The developed charging system and the way of charging should be the same for all aircraft in order to ease implementation. OEMs and associations work together on this.

Operating an electric aircraft at an airport is slightly different compared to a kerosene powered aircraft. Charging the aircraft implies new or adapted safety measures. **Manufacturers** could take a pro-active role in helping **airports** and its handling partners but also fire fighters to have a clear understanding of what is needed, in collaboration with the **authorities** (regulators).

Challenges for manufacturers, and especially in the Netherlands, is executing test flights and experimenting with the aircraft. The government, together with the autorities, could play a role in here to ensure that more room is created for experimental flights.

Aviation authorities and associations

Before a newly developed aircraft model may enter into operation, it must obtain a type certificate from the responsible aviation regulatory authority. In Europe and for some European non-EU Countries this is EASA. If a region is regulated by the FAA (US for example) then the EASA certification is reviewed by the FAA [5].

As airworthiness regulations are based on conventional aircraft with a fossil fuel powered power train, adapted regulations are needed for electric aircraft. EASA offers under special conditions the possibility to certify aircraft with an electric power system with CS23. This certification process is applicable for commuter aircraft having up to 19 passenger seats. EASA have not yet published conditions for CS25 used for large airplanes.

A close collaboration with the manufacturers will help in updating the regulations as new insights can be incorporated. Besides, changes may have to be made to regulations and standards regarding Maintenance Repair and Overhaul (MRO) and pilot training.

As for the airport and its infrastructure, a new power system and new infrastructure on the airport will require an update on the safety regulations and standards at the airport.

The civil aviation authorities are responsible for setting, monitoring, and enforcing safety standards across the local aviation environment. In the Netherlands this is done by the Human Environment and Transport Inspectorate (in Dutch: ILT). In Aruba and Curaçao this is the DCA and CCAA, respectively.

The International Civil Aviation Organization (ICAO) sets standards and recommended practices for the aviation sector. These guidelines are embedded in European legislation [6]. For electric aviation, it is important that new standards and practices are developed in pace with the developments in order to be able to have a swift implementation. The government could play an encouraging role in here.

Other associations, such as EUROCAE develop standards for aviation. Currently, EUROCAE is also developing standards for charging infrastructure for electric aircraft in their working groups, together with OEMs. Standardization is essential for OEMs as it gives guidance for their developments.

The Air Navigation Service Providers

The Air Navigation Service Providers are responsible for the safe and efficient passage of aircraft in the airspace and on the airport platforms. This also include the communication navigation and surveillance systems, the aeronautical information services, meteorological services and even search and rescue services.

For the implementation of electric flight, the ANSP will have to make sure that the electric aircraft are guided safely through the airspace. It is likely that with the introduction of (smaller) electric aircraft more movements simultaneously occur at different altitudes. This may impose challenging situations for air traffic control. Therefore, the ANSP should together work with the government **and authorities** on solutions for the airspace challenges. This is currently brought under for example SESAR 3 Joint Undertaking, a European partnership between private and public sector partners, which aims to accelerate the delivery of the Digital European Sky through research and innovation [7].

The airline

The airline plays an important role in the transition to electric aviation. Without their ‘buy-in’, the transition will not even start. For an airline, a feasible business case is key. Traditional long-haul airlines may be less likely to buy aircraft that differ to much in capabilities from their current fleet. For them to acquire smaller aircraft like 9- and 19-seats, requires a revision of their business model. In the early years it may even be not profitable and attractive to invest in electric aircraft. The government could play a role in supporting risk-reducing schemes. **Airports** could lower their fees or give discount on recharging batteries.

The investment cost of the electric aircraft may be higher than a similar model powered by kerosene, but the operational and maintenance cost will be lowered. It is estimated that operating cost will be reduced by

50-70% [8]. Alternatively, new business models could arise due to the specifics of the sustainable short range small aircraft for existing or new airlines.

The airline will have to integrate the electric aircraft into the existing network and adjust it if necessary to meet new flight range, flight time and turnaround times. These changes in operating times may also have an impact on crew planning and number of crew members required.
When adopting electric aircraft into the fleet, airlines have to offer extra training to their pilots and cabin crew. Also airport handling **and MRO personnel** must be trained, or specialized providers hired. If handling and maintenance is done by the airline, specialized equipment and spare parts are needed.

Upscaling production of aircraft that are developed 'from scratch' may take some time. Therefore, for an airline to acquire an aircraft and have it flying within reasonable time, requires a timely start of the acquisition process.

The airport

The airport has to make sure that it can handle all aircraft in a safe and efficient way. The introduction of electric aircraft means that there may be more movements on the platforms when larger flights are replaced by smaller electric variants. The airport needs to be prepared for this. Next to this, the airport will need to invest in the required charging infrastructure. The choice of infrastructure is dependent on the aircraft developments and standardization of charging infrastructure. So in fact, the airport is dependent on what **OEM**s are going to do and the **authorities** and **associations**.

In addition to charging infrastructure, suitable energy provision to the airport should be available. For this, the airport is dependent on the **energy producer**, the **network operator** and the **energy provider**.

Charging electric aircraft will require a lot of energy and peak demand. The **energy provider** should be able to provide these amounts of energy and the network operator will have to ensure the electricity network is robust enough. For actual zero-emission flight, the energy retrieved should be completely renewable sources. Energy from renewable sources could be buffered in an energy buffering system. This system could be used during peak hours when the electricity grid is not able to provide enough power. The energy provision challenges that arise with the introduction of electric aircraft is one to pick up early. The **government** can play a role in this, in stimulating that electricity networks will be upgraded and to ensure that energy is sourced renewably.

Apart from the energy providers, the airports are also dependent on **EASA** and **ICAO** for clear regulations and standards on for example training, handling, maintenance and operations. For a safe and convenient transition regulations and standards should be in place before implementation of electric aircraft. Furthermore, airports will also build on guidelines from **associations** like ACI for the kind of infrastructure to be purchased such as the type of charging stations or a universal charging system.

When accommodating electric aircraft at the airport, ground staff and the fire department should be trained. The airport will have to integrate the electric aircraft into the existing network and adjust slots and upgrade capacity, if necessary, to meet new turn around times.

In addition, to make electric flying more attractive for airlines, the airport could reserve certain slots only for electric aircraft, by adjusting the airport taxes for electric aircraft or even with incentives on landing and take-off charges.

The energy provider

One of the big challenges for electric aviation is the high energy demand is poses. Especially upscaling the number of electric aircraft charging simultaneously at an airport makes it challenging. Moreover, doing this in a green way requires even more investments.

To cope with the high energy demand the **network operator** has to make sure that the electricity network is ready to deliver this. Especially at peak hours this could be a challenge, as this already is the case in certain areas of Amsterdam [9]. The combination with renewable sources make it more difficult due to fluctuating supply and demand. Power storage at the production site or at the airport might be necessary to provide enough energy during peak charging hour at the airport or to store the renewable energy. The energy provider should prepare an impact assessment on business model to see if it will also become the new 'fuel provider and handler' at the airport for energy and infrastructure.

The challenges that arise in this transition are not small. The **government** could play a supporting role in providing subsidies for renewable energy, drafting policies that accelerate the transition towards renewable energy sources or create a tax scheme where fossil energy is charged higher than renewable energy.

The educational institutes

Educational institutes will play a key role in training air and ground personnel. To be in time with the implementation of electric flight, schools will need to adapt their programs right now.

Universities and knowledge institutes could support the development of new technologies through R&D activities and work together with OEMs. For example, they could play a role in the research into technologies which will help development of larger aircraft, increase the range and optimize the charging time. This is already being done in EU programs such as Clean Sky, but could also be done on a smaller scale with shorter runtimes or 'living labs'.

R&D activities tailored to electric flight and sustainable aviation in general are important for the industry's transition. The **government** can play a role in (partly) subsidizing R&D activities that contribute to making avation more sustainable.

The government

The government can play multiple roles in the development of the electric flight ecosystem. A stimulating and facilitating role is essential, especially in the early ramp-up years.

The government could play a role in easing the implementation of new technologies by accelerating the legislation and standardization processes. Since this is not only a national affair it is key to have an international collaboration on this subject.

The ramp-up years might not be economically attractive for airlines or other aviation businesses to implement new aircraft technologies. The risk could result in long waiting time before ordering. Therefore, governments could incentivise the acquisition and operation of electric aircraft and required/associated infrastructure by offering supporting schemes or grants for airlines and airports.Taxation of aviation fuel or exemption of taxes can be used to either create a level playing field or stimulate the business case for electric aviation.

The transition to sustainable air services could be stimulated by using a public service obligation (PSO). A PSO is an obligation imposed on an organisation by legislation to provide a service of general interest within EU territories. In order to maintain appropriate scheduled air services on routes which are vital for the economic development of the region they serve, the Netherlands may impose public service obligations on these routes. There are two options:

- by awarding exclusive rights to those running public services, compensating them financially, or/and
- by defining rules for how public transport is operated.

Another example of how government can play an stimulating role is through the National Growth Fund towards Sustainable Aviation "Groeiplan Duurzame Luchtvaart 2021". The aim of the growth funds is to stimulate the Dutch sector in order to be able to contribute significantly to making the aviation ecosystem more sustainable.

Furthermore, the following European and global guidelines will help support the implementation of electric aircraft:

- The EU Taxonomy for Aviation addresses the future European rules related to sustainable aviation.
- Enforcement of CORSIA will stimulate airlines to investigate the possibility to transition to renewable alternatives.
- The European aviation sector published in February 2021 Destination 2050, where a route to net zero European aviation is proposed.

In addition, on international level the following areas require attention:

- Regulation regarding operations of an electric aircraft at an airport. This includes safety requirements regarding fire fighting but also guidelines regarding the charging process and the circulation of the aircraft at the airport (landing, taxiing, parking and take-off).
- The standardization of charging stations and charging operations.

4.3 Conclusion

In the previous section an overview was given of the stakeholders, their role, dependencies and possible actions to enhance the transition. It became clear that many of the stakeholders are dependent on each other's action. Posing the question: who is going to take the first step? This is still a hard question to answer. At least it is clear that collaboration of the stakeholders is very important as the implementation of electric aircraft involves a system change in which everyone needs to act. The roadmap in chapter 9 gives an clear overview of which stakeholder has to do what within a given time period.

It is suggested to create a dedicated platform where stakeholders meet and exchange information, needs and ideas in a practical way. This platform could act as a working group, in which is worked together towards the transition. The existing initiatives in the Netherlands such as AHEV and Power Up are good examples of collaboration between airports, educational institutes, businesses and government on a higher level. Despite these and other existing sustainable aviation initiatives a more practical working group could help in taking the first steps, eventhough these may be on a small scale or in living lab environment.

It could be that a group of airports take place in this working group or at least a logical combination of airports for who electric flight might be an interesting modality for their airlines. Obviously, the case of the ABC-islands is perfect here. Looking abroad, the by Avinor initiated working group in Norway is a good example collaboration, where also the practical considerations are taken into account.

5 Technology

Electric aircraft make use of multiple technologies that are already on the market, for example in the automotive industry: batteries, (fast) chargers, electric motors, battery management systems, etc. However, many of these technologies are not fully tailored yet and need more advancement to create an aircraft with sufficient range and passenger capacity. Barriers in the development are the very stringent safety and airworthiness requirements in the certification process; although there is good reason to have them, it can prolong the development path by years. Moreover, flying electrically requires high-energy density batteries. At the same time, to maintain a healthy business case, aircraft need to be in the air as much as possible, demanding short turnaround times and thus quick recharging of batteries. Therefore, manufacturers of aircraft, chargers and especially batteries are challenged to increase the capabilities of the components. This poses the question: where are we today and what needs to be achieved to bridge the gap?

In the following sections a brief overview is given of the current developments on aircraft design level, batteries, charging infrastructure and energy supply.

5.1 Aircraft development

Electric aircraft development started to pick up pace after the introduction of several small electric aircraft like the Pipistrel Alpha Electro between 2010 and 2020. At this moment, there are about 100 electric aircraft programs running, from which almost half of it is initiated by start-ups [10]. An overview of a selection of electric aircraft and their expected Entry Into service (EIS) can be found in the image below.

In general, the following types of aircraft are being developed:

1. General aviation and recreational aircraft,
2. Urban Air Taxis,
3. Regional and business aircraft,
4. Large commercial aircraft.

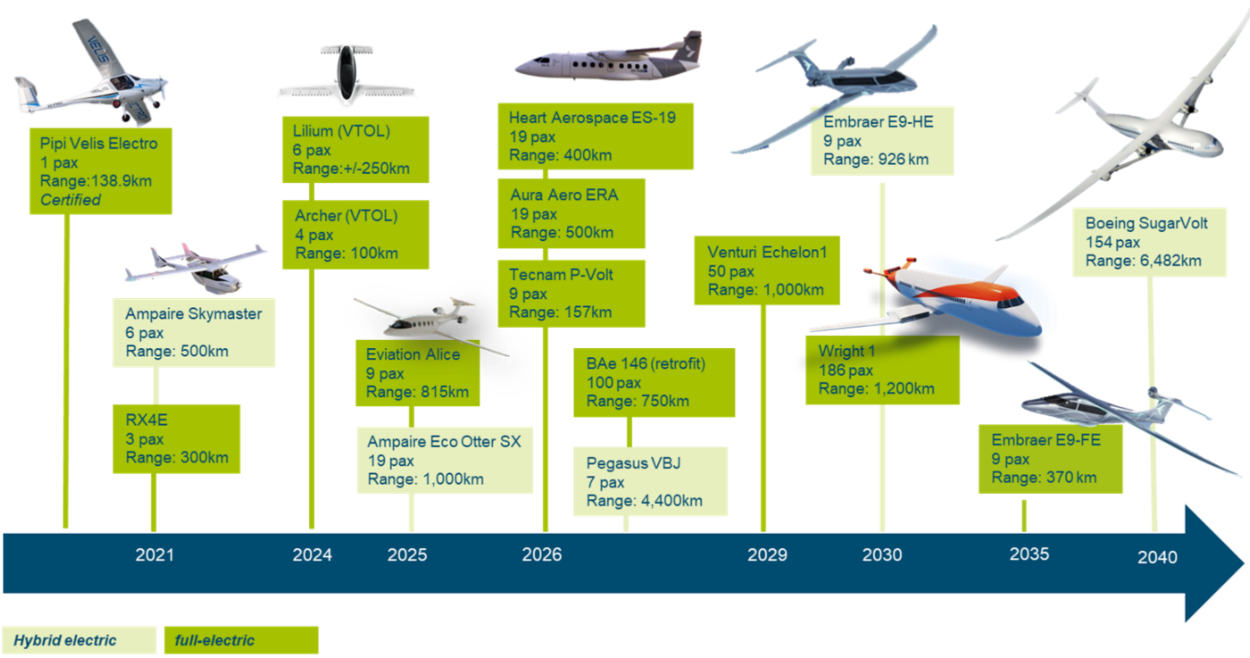


Figure 3 - Selection of aircraft development programs projected on the timeline with communicated EIS year (source: author)

1. General aviation and recreational aircraft

General aviation and recreational aircraft are smaller aircraft, typical with one, and sometimes with two, propellors. Mostly it seats two to four passengers. Some development programs have started from scratch, other programs are using existing airframe designs. Alternative programs re-use existing aircraft and retrofit them with a parallel electric powertrain, such is being done by Ampaire. The latter can offer advantages in the certification process, as not the whole aircraft needs to be certified.

Currently, the Pipistrel Velis Electro (Figure 4) is the only electric aircraft that has been EASA certified within this segment. The general aviation is seen as the test bed for further development of larger electric aircraft.

Figure 4 - Pipistrel Velis Electro (source: Royal NLR)

2. **Urban Air Taxis**

Urban air taxis are small all-electric vehicles that mostly seat up to 4 passengers for a limited range up to 100-200 km. Urban air taxis are quite often featured by distributed propulsion or multiple rotors and are able to take-off and land vertically. That is why they are also called Vertical Take-Off and Landing (VTOL) vehicles. These vehicles are typically designed to hover over urban areas without polluting or producing too much noise – called Urban Air Mobility (UAM). An example of such an initative is the Lilium Jet, with a range of 250 km and room for 6 passengers. The Lilium Jet is propulsed by 36 ducted fans which are distributed over the wings. Lilium plans to launch their VTOL commercially by 2024 [11].

Figure 5 - Lilium Jet (source: Lilium)

3. Regional and business aircraft

Regional and business aircraft are aircraft that can carry up to 19 passengers for a range of 500 – 1,000 km. Regional aircraft could be used for short-haul flights between cities or as a feeder to larger hubs. For certain destinations this could be an alternative to railroad transport, in special at locations where it is too expensive to invest in railroad infrastructure. Regional air mobility (RAM), as it is called, is also interesting for (rural) areas with multiple airports within a <1,000 km range, for example Norway or the ABC-islands, or for airlines that have difficulties with reaching full seat utilization.

The regional aircraft that are currently being developed are both based on all-electric and hybrid-electric powertrains. An example of all-electric aircraft is the Eviation Alice, a 95%-composite 9-seater aircraft that can fly up to 800 km (planned EIS: 2024). Another all-electric aircraft that is currently being developed is the aluminum Heart Aerospace ES-19, which seats 19 passengers for about 400 km (planned EIS: 2026) [12].

Figure 6 - Eviation Alice, all-electric 9-seats aircraft (source: Eviation)

Figure 7 - Heart Aerospace ES-19, all-electric 19-seats aircraft (source: Heart Aerospace)

A hybrid configuration, recently launched by the non-startup company Embraer, is the Embraer Energia Hybrid, offering a range of 500 Nm (926 km) for 9 passengers (planned EIS: 2030) [13].

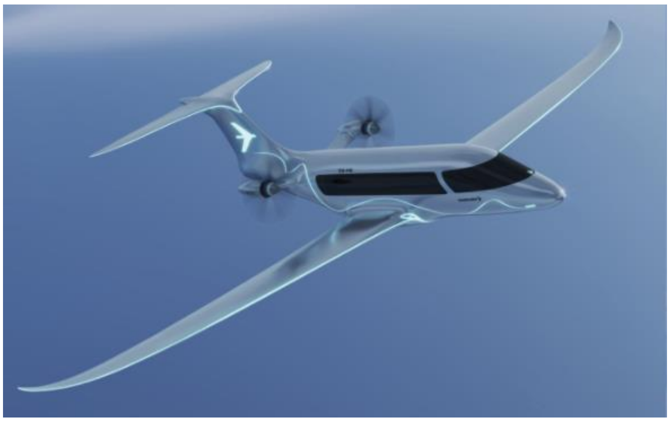


Figure 8 - Embraer Energia Hybrid (source: Embraer)

4. Large commercial aircraft

A few large commerical aircraft development programs have been launched, most of them by the established OEMs, such as Airbus and Boeing. Airbus has brought its demonstrator project under the E-fan X program and Boeing is working on the Sugar Volt project. A newcomer in this category is Wright Electric, which aims to retrofit a Bae 146 into an all-electric aircraft. This aircraft should be able to carry 100 passengers on routes like Frankfurt-Paris. Planned EIS is 2026 [14].

Figure 9 - BAe146 retrofit Wright Electric all-electric aircraft (source: Wright Electric)

It should be noted that some aircraft developers tend to present ambitous plans and performance numbers. Some reservation is required here, as certification may delay the promised EIS by years. Another reservation could be made on the communicated range: some manufacturers aim for the increase in energy density of batteries, which still can be disappointing, resulting in a lower range than initially is advertised.

5.2 Battery development

Similar to the automotive sector, lithium-ion (li-ion) batteries are most commonly found in electric aviation nowadays. Li-ion batteries have one of the best energy-to-weight ratios. Furthermore, the batteries are featured by a low self-discharging rate and a high open circuit voltage [15].

Although the specific energy density of li-ion is relatively high compared to other chemistries, it is still not sufficient for larger electric aircraft. Current li-ion batteries offer as much as 250Wh/kg. Compared to kerosene this is 50 times lower. This means that there is a gap to close to be able to carry at least a part of the passengers that is transported by a kerosene powered aircraft.

Other disadvantages of li-ion are the battery life and performance over time, its robustness with respect to overcharging and discharging, their fragility and their sensitivity to high temperatures This results in stringent safety requirements for onboard battery packages and tailored fire fighting protocols.

Example: Bauhaus Luftfahrt developed a concept aircraft “Ce-liner” for 189 pax, range 1,667 km. Powered by two electric fan engines, this aircraft would need 2000 Wh/kg battery packages(!) [16]. This is out of reach for li-ion. Other battery solutions are needed, such as lithium-sulfur batteries or lithium-air/oxygen. The latter may achieve an energy density of 750 Wh/kg within 15 years, up to 1400 Wh/kg within 30 years [17]

5.3 Charging technology

Existing airports are not designed for servicing electrically charged aircraft. It is necessary to adapt the infrastructure of the airport. Especially the electric network needs to be adapted in order to be able provide sufficient energy to the aircraft, besides ground storage and distribution. A certain number of recharging points is necessary dependent on the schedule and predicted fleet, which imply a certain consumption of electricity.

Optimization studies can help to size the infrastructure in terms of optimal charging schedule and necessary equipment for smart charging. The sizing is a.o. dependent on the airport departure schedule and technological properties of the aircraft and airport, i.e. batteries and chargers.

Electric aircraft can be charged from fixed charging stations or mobile charging stations. Charging an aircraft needs to be done swiftly in order to be competitive with regular turnaround times. For smaller aircraft like 9- and 19-seats, the preferred maximum turnaround time is 30 minutes. Therefore, fast chargers are essential for electric aviation. However, fast charging would impact peak power required from the grid and the required robustness and capacity of the airport energy grid. Besides, the battery needs to be designed for fast charging; for Li-ion batteries, charging has to be performed within a temperature range of 5-45 degree Celsius. This asks for built-in heating or cooling systems, or specific charging environments as seen in the automotive industry.

Battery Swapping Stations

Battery Swapping Stations (BSSs) would overcome the limitations of charging time and temperature constraints, where depleted batteries can be swapped by fully charged ones. While this method looks very attractive to the an airport or airline, it comes with some challenges BSSs are costly as you need a (robotic) infrastructure for the station as well as much more space than a regular charging point [18]. Besides you would need multiple batteries, which is an investment. Another limitation is the aircraft itself: it needs to be designed to have an easily removable battery and the battery systems need to be standardised. Furthermore, the battery itself must be designed in a specific way in order to be easily swapped [19] [20].

Replacing the battery is seen as a separate maintenance task, which requires specialized personell. Safety checks and the time it takes to replace the batteries would still take quite some time, as it is not a small battery that is to be replaced. Moreover, designing swappable batteries and aircraft result in additional certification challenges, prolonging the trajectory which is already quite extensive. This is why manufacturers noted in interviews during this study that BSS is not considered a feasibile option for a recharged battery. It is expected that in the coming years regular charging remains the standard for electric aircraft.

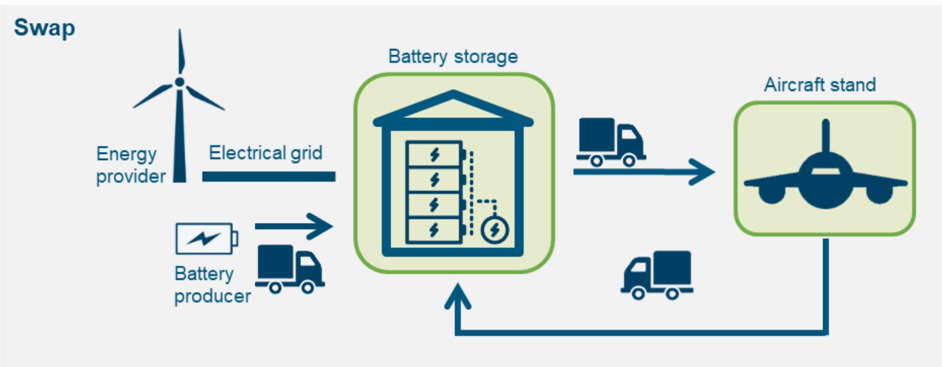


Figure 10 - High-level visualization of a Battery Swapping Station process (source: author)

Plug-in charging

Charging technology is under continuous development in the automotive industry and other sectors such as shipping and trucks. For automotive, however, the urgency to realize megawatt-chargers is lower than for aircraft. Cars are standing still quite often and can therefore easily be recharged. Currently, for automotive applications ABB has developed a 350kW fast charger [21].

Heavy duty vehicles, like trucks, carry much larger batteries and therefore require larger chargers to maintain reasonable charging times. For heavy duty vehicles, experiments have been carried out with Megawatt Charging Systems (MCS) up to 3.75 MW (at 3000 A/1250V). It is expected that this charger will become market ready within one or two years from now. This might be very interesting for aviation, although it requires careful design of cabling, connectors and charging inlet [22].

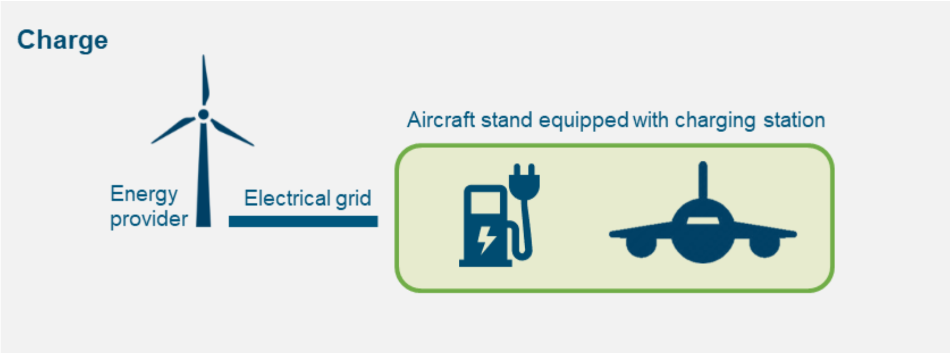


Figure 11 - High-level visualization of plug-in charging process (source: author)

Standardization

Another step in implementing electric aviation is standardization of charging technology and protocols. In the automotive industry charging is standardized. The standardization is currently being developed under EUROCAE, SAE and ASTM working groups.

5.4 Energy supply

Electric energy can be drawn from the grid or produced at the airport. When electric energy is drawn from the grid, this can be done on an as-needed basis. This however means that the electricity grid will deal with high peak powers, which must be able to meet the demand. Large, irregular electricity consumption can cause fluctuations in the supply power quality, voltage instability and increased loss of energy. A way to regulate this is to incentivize the user to reduce energy usage at peak times and distribute it over off-peak times. However, for airport schedules and power demand this may be more complicated.

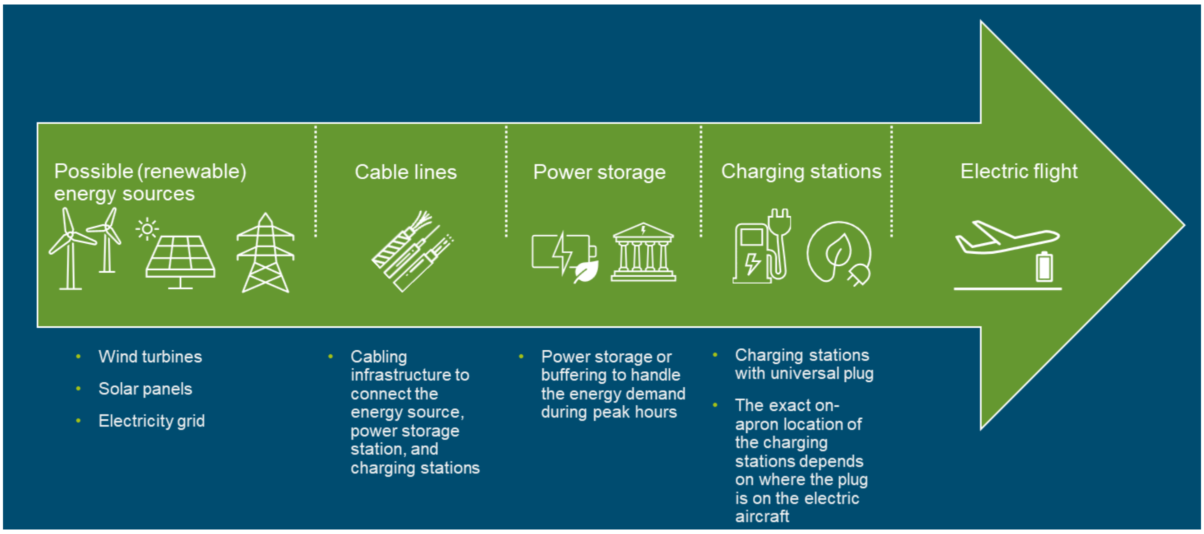


Figure 12 - Energy supply chain for zero-emission flight (source: author)

Additionally, the airport can produce electricity on site as mentioned before. A requirement for this, is that this happens in a sustainable way, thus through solar panels, wind- or water energy. The caveat with this however, is that the supply of these sources will not be continuous, as it is highly dependent of the weather and atmospheric properties, which change swiftly. A way to assure continuous supply is to store the energy generated at designated facilities, from which then energy is supplied to aircraft as needed.

As the charging of the aircraft will rely on the provision of power a high delivery certainty is required. To make sure enough electricity is available during operation times at the airport, an energy buffer or storage is advised – not only for redundancy, but also to cope with the differences in supply and demand.

Finally, it is important to note that a flight is only net zero is the energy source and the full supply chain is green.

5.5 Conclusion

At the moment, numerous electric aircraft projects have started. However, due to the current technological limits, range and passenger capacity are still relatively low. The introduction of fully electric 9-seaters and 19-seaters is expected before 2030. Besides, VTOLs are expected in this time range, offering local air transportation services between cities or rural areas. Regional air mobility services with 9- and 19-seaters are very interesting opportunities for the Dutch regional airports. Short-haul flights up to 750 km could be partly replaced by (hybrid) electric flights.

Uncertainties to achieve this timeline are the certification processes and upscaling production. Prolonged certification processes are costly for the OEMs; getting enough funding may be challenging too. For airlines, it may be not profitable yet to fly electric aircraft in the early years. Taking this first step of investing in electric aircraft might be difficult, resulting in a delay of the whole transition. Next to aircraft development, the energy infrastructure will become a challenge in the transition towards electric flight. Both on production side as well as the airport part large investments are needed to be able to provide enough energy to the aircraft.

In the longer term, towards 2050, (larger) electric aircraft with increased battery capacity are expected to enter into service. Depending on the further evolution of the aviation system in the Netherlands but also in Europe and globally, this may impact the current way of flying and the characteristics of the airports.

The penetration rate of electric aircraft in the current fleet depends on the airport infrastructure and energy provision: proper charging facilities, including safe and efficient operations must be in place.

6 Aviation at ABC islands

In this chapter, an overview of the aviation system of the ABC islands is presented. First a brief overview of the geographics of the islands is given. After that the airports, airlines and governance are described. At last, the existing energy infastructure is treated, as energy infrastructure will become a essential part of electric aviation.

6.1 Geographic situation

The ABC islands consist of Aruba, Bonaire and Curaçao and belong to the “Benedenwindse” or Leeward Islands of the Lesser Antilles. The islands are located close to the north-eastern Venezuelan coast. The distances between the islands are relatively short and all well below 200 km.

Figure 13 - Overview of the ABC-islands and the distances between the islands (source: Maperitive)

A constant and reliable demand for travel is observed between the islands, both for business and private purposes. For many inhabitants, air transport is not only an important means of transportation, but it is often the only means available. In 2019, roughly 150,000 passengers travelled by air between the islands and mostly between the airports of Curaçao and Aruba and Curaçao and Bonaire [23].

The point-to-point character of the connectivity and at the same time the short distances make it very suitable for the introduction of electric aircraft. The inter-island connections have great potential to be replaced by electric 9- and 19-seaters once the necessary infrastructure is there.

6.2 Airports

Each island has its own international airport. An overview of the airports is given in Table 2.

Table 2 - Overview of airports at the ABC-islands (source: images taken from Google Earth)

Aruba International Airport
Aruba International Airport is the busiest airport of the ABC Islands, with 29 different airlines that contribute to the process of around 2.5 million passengers in 2019. The airport is a code 4E and has one runway of length and width 2743 x 45 m. There is one main platform to park wide and narrow body aircraft in front of the terminal. Between the parallel taxiway and the runway there is a second apron for small aircraft used for regional flights between the islands.

Bonaire International Airport
Bonaire International airport has one runway of 2,880x45m that handled 390,000 annual passenger in 2019, of which 150,000 were regional passengers from the neighboring islands. The airport has a platform with capacity for four aircraft in front of the terminal building which is mostly used for the regional flights.

Curaçao International Airport
Curaçao International Airport (Hato Airport) is the second largest airport of the ABC islands. It manages 1.6 million passengers with regional destinations and destinations in Europe, South and North America. The airport apron comprises a total of 33 aircraft parking spaces, of which six for narrow-bodied aircraft.

6.3 Airlines operating between the ABC islands

Several airlines operate at the ABC islands. Amongst them are also international airlines, such as KLM. For the use case only the local airlines that operate domestic flights between the islands are considered. It should be noted that connections to the windward islands are also not considered in this study.

Most of the airlines that fly the routes are flying 9- and 19-seaters, the most important ones are Divi Divi Air and EZ Air. An overview of the airlines is given below.

Divi Divi Air

Divi Divi Air was founded in 2001 and is based at the airport of Curaçao. An overview of their fleet is given in Table 3. Two types of aircraft are in use and both are utilized for the inter-island connections.

Table 3 - Overview of routes and fleet of Divi Divi Air

Routes Divi Divi Air	Frequency	Aircraft in use	Number of aircraft	Seats per aircraft
Curaçao - Bonaire	Hourly	DHC-6 Twin Otter	4	19
Curaçao - Aruba	Every two hours	BN-2P Islanders	3	9

EZ Air

EZ Air was founded in 2008 and is based at the airport of Bonaire. An overview of their fleet is given in Table 4.

Table 4 - Overview of routes and fleet of EZ Air

Routes EZ Air	Frequency	Aircraft in use	Number of aircraft	Seats per aircraft
Curaçao - Bonaire	4/day	Beechcraft 1900D	2	19
Curaçao - Aruba	2/week			

Aruba Airlines was founded in 2006 and is based at the airport of Aruba. An overview of their fleet is given in Table 5. Two types of aircraft are in use. The Bombardier is used to fly both the routes between the islands. The Airbus A320 is used very occasionally.

Table 5 - Overview of routes and fleet of Aruba Airlines

Routes Aruba Airlines	Frequency	Aircraft in use	Number of aircraft	Seats per aircraft
Aruba - Bonaire	2/week	Bombardier CRJ200	1	52
Curaçao - Bonaire	Weekly	Airbus A320-200	1	180

Winair was founded in 1961 and is based at the airport of Curaçao. An overview of their fleet is given in Table 6. The ATR42 is used to fly the routes between the St Maarten and the ABC islands, the Twin otter is used for the route between St Maarten and St Eustatius airports.

Table 6 - Overview of routes and fleet of Winair

Routes Winair	Frequency	Aircraft in use	Number of aircraft	Seats per aircraft
St Maarten – Curaçao – Bonaire - Curaçao – St Maarten	3/week	ATR42	1	48
St Maarten- Curaçao-Aruba – Curaçao – St Maarten	3/week			
St Maarten – St Eustatius	Weekly	DHC-6 Twin Otter	3	19

6.4 Governance and aviation authorities

Governance

Aruba and Curaçao are constituent countries of the Kingdom of the Netherlands along with the Netherlands and Sint Maarten. Both countries have their internal autonomies.

Bonaire is part of the three special municipalities of the Netherlands, together with Sint Eustatius and Saba. The special municipality of Bonaire is comparable to a Dutch municipality and carries similar functions, but unlike normal municipalities, they do not form part of a Dutch province. The powers normally exercised by provincial councils within municipalities are divided between the island governments themselves and the central government.

Aviation authorities
For Curaçao and Bonaire the The Dutch Caribbean – ANSP is an Air Navigation Service Provider is responsible for traffic. They provide the Air Traffic Services (ATS) within the Curaçao Flight information region. They operate three facilities: Area Control Centre located in Curaçao and two Aerodrome Control Towers, one located at Curaçao International Airport and the one located at Bonaire International Airport [24].

For Aruba airport the ANSA, Air Navigation Services Aruba, is responsible. They provide the ATS within the Beatrix Control Zone and operates the Aerodrome Control Tower of Aruba International Airport [25].

6.5 Energy infrastructure

For the implementation of electric and sustainable flight at the islands, a reliable and sustainable provision of electric energy is essential. Electrification of aviation asks for sufficient electric energy to meet the demand. To make electric aviation actually sustainable, this energy should be generated renewably. To assess if the islands are able to provide in this, an analysis is made of the existing energy infrastructure.

6.5.1 Sustainable energy potential

According to the Köppen climate classification, the ABC Islands have a BWh and BWk climate, comparable to hot desert climate that exists in parts of Australia. A short rainy season lasts from October to December/January, including storms from the northeast trade winds. These trade winds and the large amount of sunshine make this islands ideal for wind and solar energy generation. Although the islands have great potential for renewable energy, still a reasonable amount of energy is fossil based.

6.5.2 The renewable energy provision on the islands

In the following section an overview is given of the current sustainable energy initiatives at the islands.

Sustainable energy in Aruba
In Aruba, the energy is provided by Water- en Energiebedrijf Aruba N.V. (WEB). The following renewable energy generation facilities are currrently present at the island:

- WEB has a wind turbine park at Vader Piet which was completed at the end of 2009. The park consists of 10 wind turbines with a capacity of 3 MW each, with a total capacity of 30 MW. The park can generate an average of 18 MW per day. The energy generation represents 12-14% of Aruba's energy production [26].
- In 2013 the Government of Aruba approved the construction of a second wind turbine park. The installation will provide 10-16% of the total energy production [27].

Sustainable energy in Bonaire
In Bonaire, the energy is provided by Water- en Energiebedrijf Bonaire N.V. (WEB). Bonaire uses both wind energy and a solar park as sources of renewable energy:

- East of Rincon, in Morotin park, 12 wind turbines of each 900 kW were installed by WEB.
- At Barcadera, a Solar Pilot with 792 solar panels, providing energy for around 60 households. This installation is a test pilot during which WEB examines the returns and the future opportunities of solar energy.

The generated sustainable energy fulfils 33% of the annual energy need of Bonaire. [28]

Sustainable energy in Curaçao
At Curaçao, Aqualectra is the local energy provider. At their website, they state that 40% of their energy is produced by renewable sources [29].
Curaçao has two wind farms installed. One in Playa Kanoa and one in Tera Kora, which were updated and completed in 2013. The parks consist of 10 turbines with a rated power per turbine of 3 MW, summing up to 30 MW. The parks provide nearly 20% of the electricity needs of Curaçao [30].

6.5.3 Conclusion

As can be seen from the gathered information above, all the islands have made a good start with setting up renewable energy production facilities. However, there is still a lot of unused potential, for both wind and solar power. For the transition to zero emission flight, it is essential that the transition to renewable energy generation keeps pace with the developments.

7 Electric flight potential

In this chapter, the potential of electric flight is investigated. This is done on the basis of an analysis of the air traffic between the islands; a detailed traffic analysis from Bonaire Airport gives insight in several parameters reflecting the substitution potential.

7.1 Methodology

To prepare the study two data sets were made available by the airports on the ABC islands:

- A detailed dataset with all flights departing and arriving at Bonaire Airport in the year 2019. In terms of movements, the dataset is representative for the other islands as well.
- A data sets of three representative days with flights departing and arriving at Aruba Airport in January 2020. This data set is not complete but can still give insight on the type of traffic at the airport of Aruba.

The following parameters were analysed:

- Percentage of movements carried out by 9-seaters, 19-seaters, 40-50-seaters and >50 seaters,
- Percentage of travelled passengers per seater-class,
- Seat utilization per seater-class.

The latter is analysed in order to be able to draw conclusions on possible replacement of the aircraft from the 40-50-seaters category.

For the analysis, the following selection of the dataset is used as a starting point, unless noted differently:

- Only inter island flights are considered[1],
- Only passenger flights are considered; general aviation, ambulance flights etc. are not considered.

7.2 Results

7.2.1 General findings all destinations

The flow of passengers between the islands was about 150,000 passengers in 2019 [31]. There is a constant and reliable demand for travel between the islands for both business and private purposes. In addition, for a majority of travellers, air transportation is the only mean of transport possible.

In addition, from all flights departing from Bonaire Airport in 2019, **89%** were going to Aruba or Curaçao.

7.2.2 The traffic from and to Bonaire airport (ABC-only)

For the flights between the islands the following results were found (also visualized in Figure 14):

- 33% of the flights was executed by 9-seaters, corresponding to 18% of the total passengers,
- 58% of all the movements was with 19-seaters corresponding to 63% of the passengers,
- 8% of the total flight movements was flown by 48-50-seaters, representing a passenger volume of 18%,
- <1% of all the aircraft movements is represented by larger aircraft (AT47, A320), covering 2% of the total passengers.

[1] Flights from or to the windward islands are not taken into account.

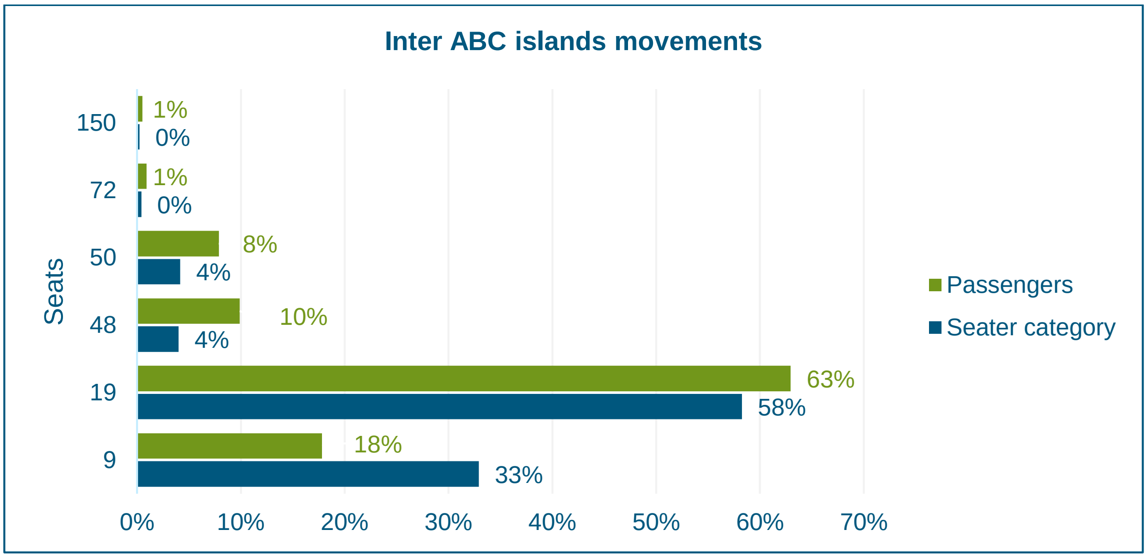


Figure 14 - Movements between the ABC-islands. Domestic flights only. Blue: percentage of used aircraft type (in seats). Green: percentage of domestic passenger volume.

The majority of the movements between Bonaire and the other two islands occurs between Curaçao:

- 98% of all departing flights is going to Curaçao; from all arriving flights this percentage is 94%.
- The flights between Aruba and Bonaire are mostly flown by larger aircraft (50-150 seats)
- In contrast to the Bonaire-Curaçao route, which is mostly flown by smaller aircraft; 91% of the movements is carried out with aircraft with less than 50 seats.

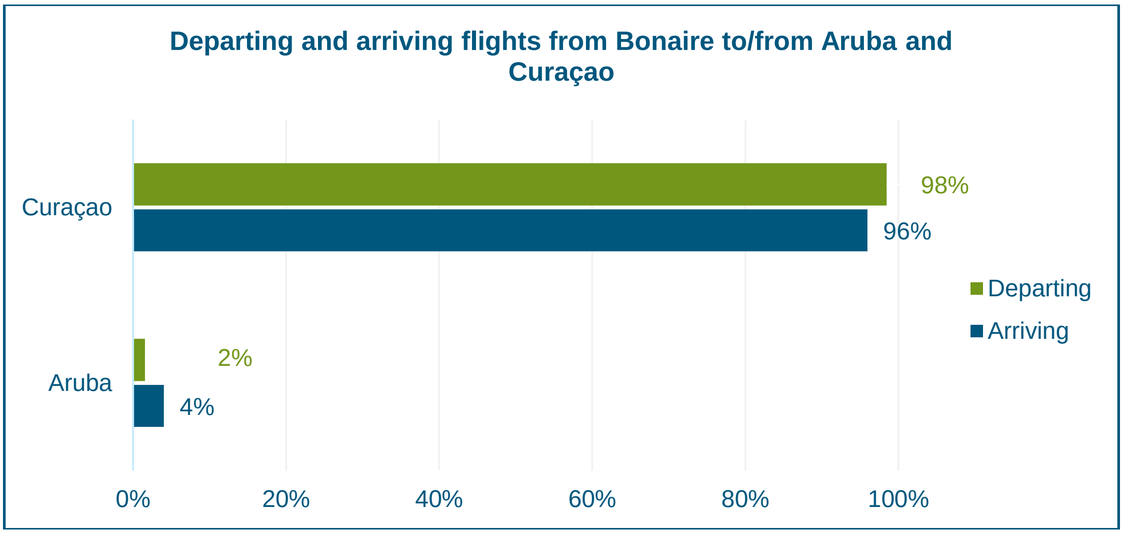


Figure 15 - Distribution of movements to and from Aruba and Curaçao

The seat occupation can be found per aircraft seat category in Table 7. It can be concluded that the 9-and 19-seaters have a relatively high occupancy. The 40-50 seats aircraft categories have a lower load factor, 54%. For this category, there may be potential to replace the flights with smaller, 19-seats electric aircraft.

Table 7 - Seat capacity and load factor per aircraft seat category

Seat capacity	Average seat occupation
9	75%
19	69%
48-50	54%
70	39%
150	18%

From these numbers it can be concluded that there is a great potential for small electric aircraft with 9 and 19 seats. Looking at the replacement of the 9- and 19-seaters this translates into almost **91% of the total traffic at Bonaire executed by its electric counterpart, carrying 81% of all passengers**.

7.2.3 The traffic from and to Aruba airport (ABC only)

An analysis was done based on the schedule that was made available for this study. The analysis was carried out on the number of flights that have been executed per aircraft type and the number of seats at the airport of Aruba. Based on the schedule, comprising 151 flights, the following was extrapolated:

- 25% of the total flights at Aruba airport was between the ABC islands of which:
  - 100% is to Curaçao,
  - None to Bonaire[2].

From the total flights between the ABC islands to/from Aruba:

- 65% of the aircraft movements were 19-seaters,
- 35% with 40-50 seaters,
- No flights were executed by 9-seaters[3].

From these numbers it can be concluded that there is a great potential for small electric aircraft with 19 seats to replace the current operations between the ABC islands. Looking at direct replacement of the 19-seaters, at least 65% of the regional traffic for Aruba could be executed by its electric counterpart. An analysis on seat occupancy (not available at the moment of writing) of the >40 seats aircraft could give insight if even more flights could be replaced by 19-seaters.

7.3 Conclusions

Based on the analyses carried out for the flight data of Aruba and Bonaire Airport, conclusions can be drawn:

- From the airport of Aruba, the flights between the ABC islands have most frequently the destination Curaçao,
- From the airport of Bonaire both destinations are flown, Curaçao and Aruba, but Curaçao is the dominant route,
- The Aruba - Bonaire route is flown with larger aircraft, 50-150 seats aircraft,
- The Aruba - Curaçao route is flown for 99% with 9-, 19- or 50-seaters.

[2] As the data received to analyse the traffic at the airport of Aruba only comprises of 3 days, no flights were found to and from Bonaire airport. Nevertheless using the complete year data set from Bonaire, in the previous section, it was found that a small portion, 2%, of the ABC flights from and to Bonaire were to Aruba airport

[3] No flights were found with 9 seaters, as the data set comprises only 3 days it is not possible to conclude with absolute certainty that 9-seaters were not used to fly the routes. Compared to the Bonaire data set, it could be seen that 9-seaters were used to fly the Bonaire-Curaçao route

- The Bonaire - Curaçao route are mostly flown by 9 and 19-seats aircraft.
- From the airport of Curaçao, the information was derived from the data received for Bonaire and Aruba. The flights between the ABC islands are mostly flown by 9, 19-seats aircraft to Bonaire and with 19- and 50-seats aircraft to Aruba.

The visualization in the bellow figure represents the aircraft movements between the islands. The thicker the line the more aircraft movements take place.

Figure 16 - Qualitative visualization of passenger flows between the ABC islands

Looking at potential replacements with electric aircraft, due to the small size (mostly 9 and 19-seaters) and the short distance between the islands of not more than 200 km, the aircraft could be replaced by the electric 9-seats aircraft such as Eviation Alice and a 19-seats aircraft such as Heart Aerospace ES-19.

8 The impact of electric flight between the ABC islands

To be able to calculate the impact of introducing electric aircraft between the islands, a phasing plan was prepared. In this phasing plan, electric aircraft are introduced gradually. Several assumptions were made on the types of aircraft that will be introduced and how these will be operated. Subsequently, the results of the impact analysis are presented, including the required amount of power for charging at the airport and the necessary infrastructure to be installed by the airport. The chapter concludes with an overview of the costs for the airports and the airlines.

8.1 Defining the phases of the implementation

Based on the electric aircraft developments as presented in chapter 5, three milestones are defined: 2026, 2030 and 2035.The phasing plan will introduce electric aircraft at the islands in 2026. The number of aircraft will be increased during each phase to finally reach in 2035 a complete replacement of flights as per 2019 by electric flights[4]. The proposed milestones serve as an example of what could be achieved in the next 15 years if all steps undergo a smooth process and should be seen as an optimistic scenario.

8.1.1 Scenario for phase 1: 2026

In 2026, it is expected that the first electric aircraft are available on the market. Based on the current status of development, it is expected that 9-seats all-electric aircraft will have entered into service, such as the Eviation Alice and that hybrid-electric 19-seaters will also be available, such as the Ampaire Eco Otter SX. Therefore, 2026 is chosen as an important year for the islands. The islands can start flying the first electric aircraft.

The scenario proposed for the first phase aims to enhance the transition of the air transportation system and the engagement of all the islands. Therefore, it is assumed that in total three 9-seater all-electric aircraft will be flying between the islands. Furthermore, one aircraft is charged at the time at an airport. Therefore, all three airports require one charging station with the same charging capabilities.

The current energy infrastructure at the islands does not allow for large charging facilities yet. Therefore, it is expected that the maximum charging capabilities will not exceed 400kW, which is comparable to the power required for a fast charger for electric cars in the Netherlands today. The 400kW is a lower level than is advised by the aircraft manufacturers; they state that at least 1MW charger is necessary to be able to charge the aircraft batteries fully in 30 minutes. [12]

8.1.2 Scenario for phase 2: 2030

In 2030 it is expected that also fully electric 19-seaters will become available on the market and therefore they are introduced in the total pool of electric aircraft flying between the islands.

Based on the technology forecast, the full-electric 19-seater that is expected to have its entry into service by 2030 is the Heart Aerospace ES-19.

The scenario for 2030 proposed an additional 3 fully electric aircraft with 19-seat capacity. Similar to the previous phase, all three islands will require to charge one additional aircraft at the time resulting in one 9-seater charging station (already present since 2026) and one 19-seater charging station per airport in 2030.

It is expected that this pool of six electric aircraft will be able to cover 50% of the passenger demand of 2019.

---

[4] *Important to note is that this plan is a more ambitious than the one stated in AHEV and the Luchtvaartnota. It should be seen as an optimistic scenario that is only based on technological advancements and may be possible to achieve if all steps are taken in time.*

Over the years, it is assumed that the energy infrastructure is further developed on the islands and allows for larger charging facilities in 2030. Therefore, charging stations with capabilities of around 1MW are anticipated by then. This is in line with the capabilities advised by the manufacturers to reach a 30-minutes (re)charging time. [12]

8.1.3 Scenario for phase 3: 2035

Ultimately, in 2035, the aviation sector will have learned from operating electric aircraft for almost 10 years. Therefore in 2035, it is expected that scaling up will be possible. The aircraft pool will be doubled compared to 2030. This number of electric aircraft will be able to cover all air movements between the islands as per 2019.

This translates in an aircraft pool of in total six 19-seats electric aircraft and six 9-seats electric aircraft. The new aircraft will also be evenly distributed among the three islands. Each airport will have to host two additional stations, resulting in a total of four charging stations in 2035: two chargers for the 9-seats aircraft and two chargers for the 19-seatsaircraft.

Moreover, it is assumed that the energy infrastructure at the islands is further upgraded, enabling the installation of several 1 MW charging stations. This makes it possible to have more aircraft charging simultaneously.

As to maintain a conservative energy scenario, it is anticipated that the airlines will remain flying the same type of electric aircraft as during the previous two phases and that battery capacities remain in the same order of magnitude,

The above proposed scenarios are supported by interviews with (local) aviation stakeholders such as airports, airlines, authorities and aircraft manufacturers.

A summary of the proposed phasing can be found in the table below

Table 8 - Overview of the proposed phasing for the implementation of electric aircraft on the islands

	Total in 2026	Added in 2030	Total in 2030	Added in 2035	Total in 2030
Total pool of electric aircraft flying between the ABC islands	Three 9-seats	Three 19-seats	Three 9-seats Three 19-seats	Three 9-seats Three 19-seats	Six 9-seats Six 19-seats
Charging station(s) per airport	1 charger	+ 1 charger	2 chargers	+ 2 chargers	4 chargers

.

8.2 Operational assumptions

The following operational assumptions are used in the next steps of this study to quantify the impact of electric flight on power requirements, infrastructure and cost:

- The Eviation Alice and Heart Aerospace ES-19 were used to calculate the peak power required at the airport. Both aircraft are fully electric and are expected to be able to fly at least 200km, which is the longest distance between two islands, Aruba-Bonaire.

The specifications of the aircraft brand are:
| 9 seats | 820 kWh battery | 815 km range

The specifications of the aircraft brand are:
| 19 seats | 900 kWh battery | 400 km range

- For safety reasons, a requirement is set that aircraft reserve sufficient fuel in order to make a detour to another airfield during flight if necessary. Current regulations for VFR flight require 30 minutes of reserve time available in the battery. For smaller aircraft, like the 2-seater Pipistrel Velis Electro, this means that roughly 50% of the battery is needed to reserve 30 minutes. For larger aircraft however, this will be a lower percentage. It is therefore assumed that the 9- and 19-seater aircraft must have at least 30% of their battery left. This assumption was confirmed by the manufactures.
- Only plug-in charging is considered. Battery Swapping Systems (BSS) appear to be too complex in terms of certification and operational feasibility, as it is seen as a larger maintenance act by the current regulations. Interviews with manufacturers confirmed that it is not likely that this technology will further mature within the aviation industry. [12]
- The time for the turnaround of an aircraft is maximized at 30 minutes. This assumption is based on the flight analyses and interviews with airlines. The maximum turnaround time of 30 minutes determines the maximum charging time that is possible during a turnaround.
- The pool of electric aircraft that will fly the ABC routes will be equally divided between the islands. This was chosen to propose equal participation of the islands during the study. In addition, as the actually range of the e-aircraft might be less due to battery performance, it is advised to have equal charging capabilities on the islands such that the aircraft can eb recharged after each flight.
- A leg of 200 km is taken as maximum distance flown before charging. This allows for flexibility for the airline regarding charging scenarios but at the same time does not require too high capabilities for charging. For example: for the Heart Aerospace this represents 50% of its battery capacity if a total range of 400 km is seen as 100% battery capacity. The 200 km represents routes such as Aruba-Bonaire or Curaçao-Bonaire-Curaçao including a margin for higher power demand during take-off or due to weather conditions such as high head winds during cruise. The required power for this distance is used as input for the determination of charging requirements at the airport, to make sure the scenarios are conservative.

For each phase a scenario is defined, using the operational assumptions and the earlier determined timeline. The scenario considers the number of aircraft that will be replaced by an electric alternative, the new aircraft type, the battery capacity, the range the aircraft will fly. These scenarios give insight in the implementation requirements.

8.3 The power required at the airport for charging

To determine the required power for charging at the airport, two charging scenarios were chosen:

- The aircraft is charged after each flight with a maximum range of 200km between two charge sessions,
- The aircraft is charged once the minimum of 30% battery State of Charge (SoC) is reached which is in line with the required battery reserve for safety reasons.

Required power will be determined for both charging scenarios for each phase.

8.3.1 Phase 1, 2026: One 9-seater electric aircraft per airport

The specifications of the Eviation Alice aircraft are used to determine the charging requirements at the airports to charge the aircraft within 30 minutes.

The required power translates in the following requirements for charging, either after 200 km flown or once the limit is reached:

- Scenario 1: 200 km represents 25%[1] of the range which results in power required to charge the aircraft in 30 minutes of 400kW. This requirement is in line with the assumed development on the energy systems of the islands in the coming five years.
- Scenario 2: If the aircraft is charged once the battery reached 30% this translates to 1150kW of required power if charged in 30 minutes. Charging 70% of the battery in 30 minutes requires power levels of more than 1MW, which might not be feasible yet, given the current energy system capabilities at the islands. Therefore, scenario 2 is considered not feasible in 2026.

[1] 25% may be a bit optimistic as take-off and landing consume more energy than cruise.

To minimise power demand, it would be advised to charge the aircraft after each flight and to not exceed a distance of 200 km between two charges during operations. A full recharge is then done overnight, also to maintain battery life.

A representation of the two scenarios and the calculation can be found in the Figure *17*.

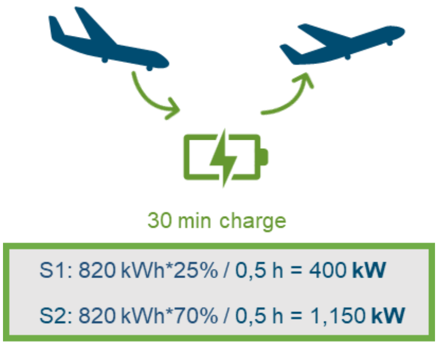


Figure 17 - Overview of charging requirements for scenario 1 and 2

8.3.2 Phase 2, 2030: One 19-seater per airport added

In 2030, the share of electric aircraft will have increased. In addition to the 2026 fleet, one 19-seater all-electric aircraft will be introduced per airport. The Heart Aerospace ES-19 specifications are used to determine the charging requirements at the ABC airports if the aircraft is charged within 30 minutes.

The required power translates in the following for charging after each 200km flown or once reaching the limit:

- Scenario 1: 200km represents 50% of the range of the Heart aircraft which results in power required to charge the aircraft in 30 minutes of 900kW. Together with the previous installed stations, a total charging capacity of 1,3MW over 2 charging stations per airport will be required. The maximum capability per station do not exceed 1MW. [5]
- Scenario 2: the aircraft is charged once the battery reached 30% this translates to 1,3MW of required power if charged in 30 minutes. Recharging 70% of the battery requires power of 1,3MW which will result in power capabilities of almost 2MW together with the existing station, which is assumed to not be achievable on the islands by 2030. Therefore, scenario 2 is not considered feasible in 2030.

A representation of the two scenarios and the calculation can be found in the bellow image:

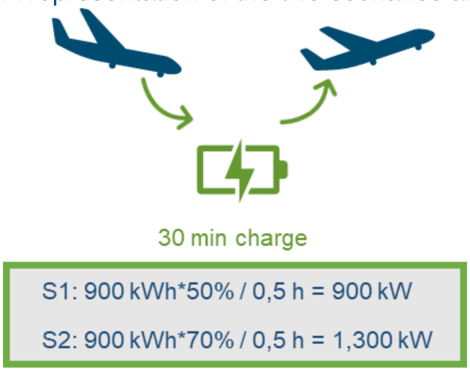


Figure 18 - Overview of charging requirements for scenario 1 and 2

During operations, to minimise power requirements on the islands it would be advised to charge the aircraft after each flight and only allow the battery to reach its minimum capacity when the aircraft will be parked longer or overnight at the airport.

8.3.3 Phase 3, 2035:one additional 9-seater and 19-seats aircraft

In 2035, the share of electric aircraft will have increased further. Assuming one 9-seater and one additional 19-seater fully electric aircraft. The charging requirements will be based on the specifications of the Eviation Alice for the 9-seater and the Heart Aerospace ES-19 for the 19-seater.

It was chosen to only use scenario 1, which is less demanding in terms of peak power demand. A maximum distance of 200km will be flown before charging the aircraft. Similar to the previous phases, the power required to charge within 30 minutes after flying the maximum distance is 400kW for the Eviation Alice and 900 kW for the Heart ES-19.

The resulting maximum charging capability of the new stations is 400kW for the Eviation Alice aircraft and 900kW for the Heart Aerospace ES-19 aircraft. This results in an additional 1,3MW and a total charging capacity, including the existing two stations of 2,6MW. The requirements are distributed over four stations at the airports.

During operations, to minimise power requirements on the islands, it is recommended to charge the aircraft after each flight and only allow the battery to reach its minimum capacity when the aircraft will be parked longer or overnight at the airport.

8.3.4 Conclusion and overview

As scenario 1 has less power requirement and is therefore more likely to be feasible to obtain such peak power requirements in the coming years, it was decided to select scenario 1 for all three phases. This

[5] Important to note is that 1,3MW of energy represents 10% of the total peak demand energy on the island of Bonaire in 2017. [32] This means the energy in 2030 will have to be considerable scaled up for this scenario.

means the aircraft will be charged after a maximum flight of 200 km. It is advised to only exceed this maximum up to the 30% battery State of Charge if the aircraft can be parked on the ground for a longer period of time (to be fully recharged). Recharging the battery after each flight is not optimal for the battery life but is more realistic in terms of power provision on the islands up to 2035.

A summary of the power requirements per phase for the chosen scenario can be found in the image below:

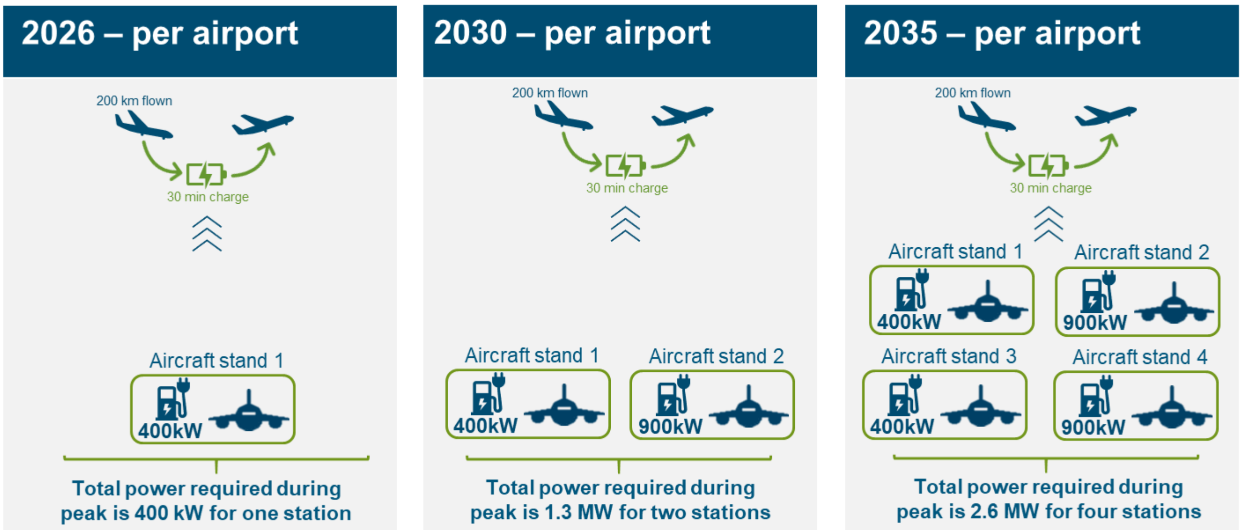


Figure 19 - Overview of charging requirements for each phase using scenario 1

8.4 Power demand translated to sustainable energy source

There are different options for the energy provision to the airport to charge the aircraft. To obtain a fully zero-emission flight, not only the aircraft has to be electric, but also the energy used to power the aircraft must come from a sustainable source.

If the energy is taken directly from the grid the emissions of the electric flights will depend on the portion of green energy provided by the energy companies. At the time of writing, the portion of green energy on the islands is approximately 30% to 40% of the total energy provided. [29] [30]

In order to give insight on the required amount of green energy source to charge the aircraft for each phase, a quantification was made for either:

- A number of wind turbines, or
- Amount of square meters of solar panels.

Both sources are well applicable on the islands due to weather conditions. In addition, the local energy providers on all three islands are familiar with the one or two of the possible sources.

8.4.1 Assumptions

The following was assumed regarding the specifications of the sources:

1) Solar energy source:
It is assumed that one square meter of solar panel installation can generate 200 W peak power. As the energy produced is depending on the solar radiation, the square meter requirements are 25% higher to assure enough power.

2) Wind energy source:

Based on the performance of the wind park of Aruba and Curaçao, it is assumed that the wind turbines have a rated power of 3 MW. [27] [29] As the energy produced is depending on the wind condition, it is assumed that the wind turbines are used at 40% part load.

8.4.2 Requirements for phase 1

In phase 1, the power required is of 400kW per airport, this translates in one of the two following sustainable energy infrastructures:

- 3,000 m2 of solar panels that is, for example, 30 x 100 meters which represents almost half a football arena.
- 1 wind turbine of 3MW rated power.

8.4.3 Requirements for phase 2

In phase 2, the additional power required is of 900kW for the new charging station per airport. It translates in one of the two following sustainable energy infrastructures:

- An additional 6,000 m2 of solar panels that is, for example, 60 x 100 meters which represents almost a full football arena.
- No additional wind turbine is required, it is assumed the turbine installed in 2026 with rated power 3MW will provide enough power for both stations.

In phase 2 the total amount of peak power will be 1,3 MW for a total of 2 charging stations per airport. This demand translates in 9,000m2 of solar panels or 1 wind turbine of 3MW rated power used each at 40%-part load.

8.4.4 Requirements for phase 3

In phase 3, the additional power required per airport is of around 1,3MW for the two charging stations, one of 400kW and one of 900kW. It translates in one of the two following sustainable energy infrastructures:

- An additional 9,000 m2 of solar panels that is, for example, 28 x 100 meters which represents almost half a football arena.
- An additional wind turbine of 3MW rated power.

In phase 3 the total amount of peak power will be 2,6MW for a total of 4 charging stations per airport. This demand translates in 18,000m2 of solar panels or 2 wind turbines of 3MW rated power used each at 40%-part load per airport.

8.4.5 Overview for each phase

A complete overview of power requirement per airport and the translation to sustainable possible energy sources is given below for each phase:

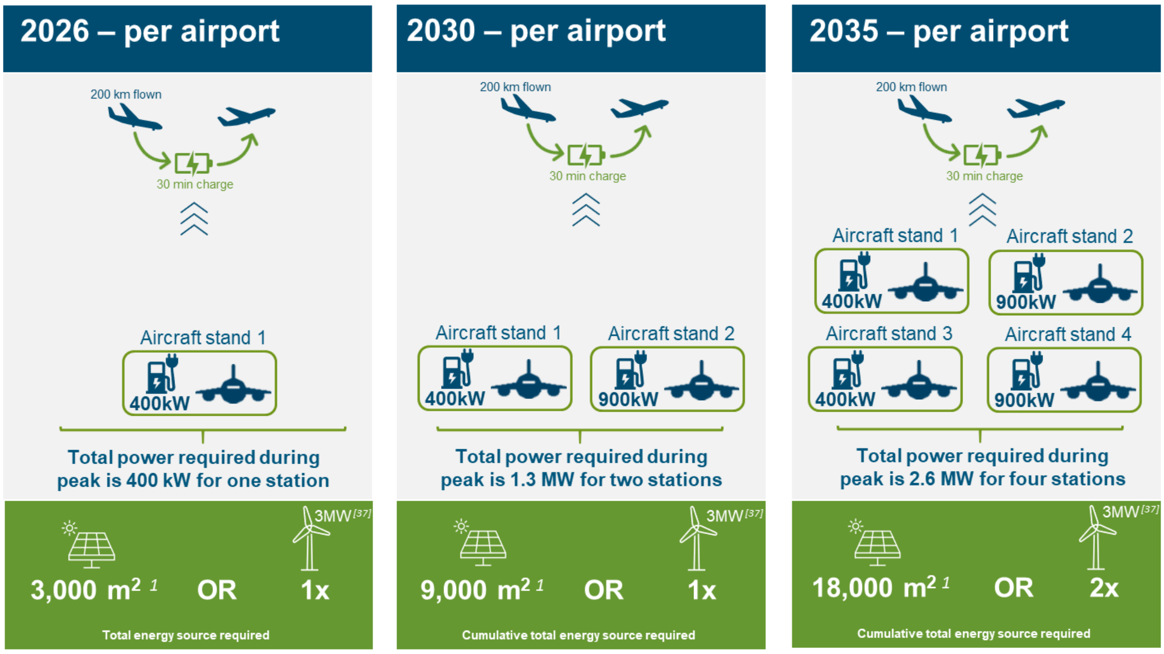


Figure 20 - Overview of charging requirements for each phase using scenario 1 and the resulting green energy source required

8.5 Airport infrastructure required for electric flight

In addition to the power provision, the airport will have to install adequate infrastructure to allow for electric aircraft operations. To get the power from the source up to the charging stations, the airport should invest in several utilities. These are illustrated in the image below for the Airport of Bonaire. Bonaire was taken as an example, and a similar set up is also foreseen for the airports of Curaçao and Aruba.

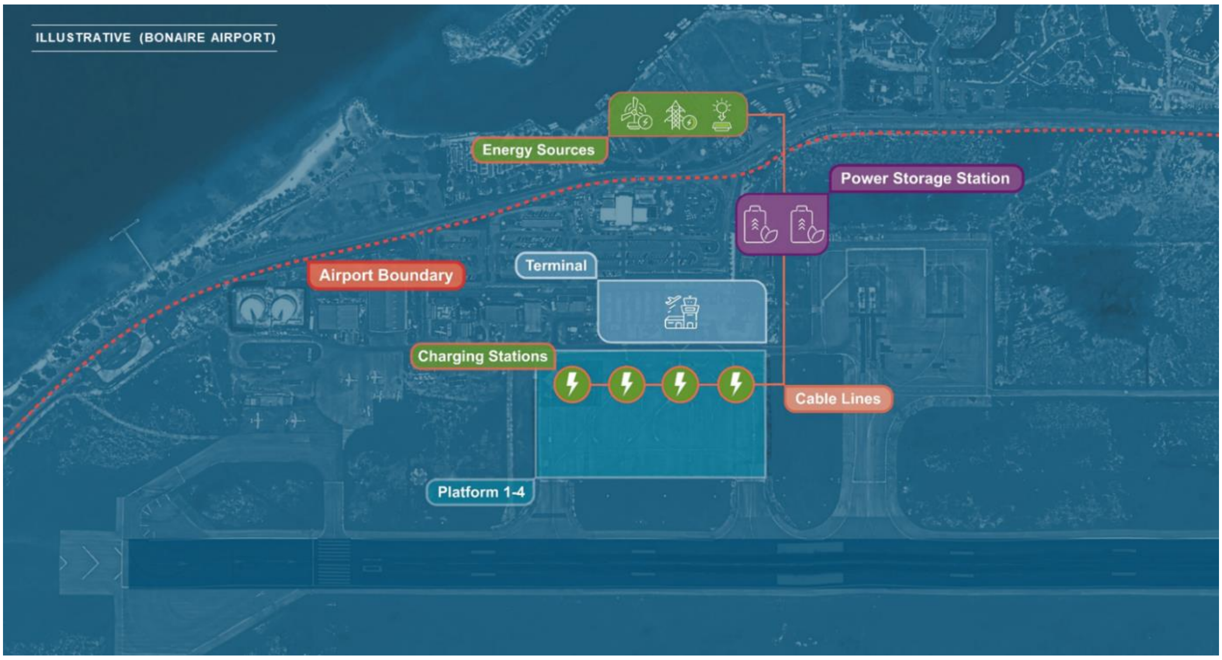


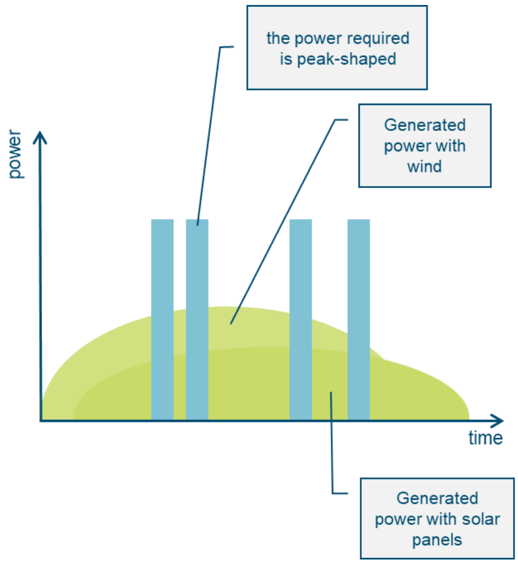
Figure 21 - Overview of the infrastructure required at the airport for electric flight (source: author and underlayer Google Earth)

The energy source is first connected to a power station which will buffer the energy, after which it is connected via cables to the charging stations. The stations have to be located on the apron; each e-aircraft stand will have its own station. The exact location will depend on where the charging point is on the aircraft.

In the next paragraph additional information is given for each piece of new infrastructure:

1. Energy storage:

As the charging of the aircraft will rely on the provision of power a high delivery certainty is required. To make sure enough electricity is available during operation times at the airport, storage is advised.
Not only for redundancy, but also to cope with the differences in supply and demand in a renewable energy system, an energy storage system is required.
The power generated by wind and sun will be constant throughout the day hours. The power demand during charging of an aircraft will give high peaks. The imbalance between supply and demand can be solved by storing the energy generated during off-peak times. Subsequently this is used during the peak hours.



2. Electric infrastructure

The higher the peak power requirements the more complex the electric infrastructure system becomes. The whole system will have to be adapted including cables, switchboards and transformers. Furthermore the grid will have to be updated and stabilized to make it robust enough to cater the high peak demand. For the numbers found in the previous section, cables of large diameter and cooled will have to be installed to make sure the high power requirements can be safely provided to the aircraft. Important tot note is that the larger the distance between the energy storage and the charging stations, the more energy is lost on the way. Therefore it is advised to install the buffering station as close as possible to the parking positions and charging stations for the electric aircraft.

3. Charging station

The power requirements for the station were calculated in the previous sections. When installing the the station, the exact location will depend on where the charging point is on the aircraft. This will have to be looked into in a later stage once more information is available on the characteristics of the intended electric aircraft.

8.6 Overview of the implementation phases for the ABC islands

The table below gives an overview of the new technology and infrastructure to be acquired per airport per phase and of the total pool of aircraft for each milestone.

Table 9 - Summary of the proposed phasing for the implementation and the resulting power provision and costs per phase

	Total in 2026	To be added by 2030	Total in 2030	To be added by 2035	Total in 2035
Total electric aircraft pool between the islands	Three 9-seat electric	+ Three 19-seat electric	Three 9-seat electric Three 19-seat electric	+Three 9-seat electric +Three 19-seat electric	Six 9-seat electric Six 19-seat electric
Maximum number of electric aircraft per airport	One 9-seat electric	+ One 19-seat electric	One 9-seat electric One 19-seat electric	+ One 9-seat electric +One 19-seat electric	Two 9-seat electric Two 19-seat electric
Infrastructure per airport	1 charging station	+1 charging station	2 charging station	+2 charging stations	4 charging stations
Total peak power required per airport	400kW	+900kW	1,3MW	+1,3MW	2,6MW

8.6.1 Phase 2026

In 2026, a total of three 9-seat electric aircraft will fly the routes between the islands and each airport of the ABC islands will have one charging station. This first phase marks the beginning of the introduction of commercial electric aircraft and is based on techonolodgy advancements as presented in chapter 5.

The image below represents the total amount of electric aircraft flying between the island and the amount of charging station present at each airport.

Figure 22:Overview of the pool of electric aircraft flying between the islands and the charging stations per airport

8.6.2 Phase 2030

In 2030, a total of six electric aircraft, three 9-seaters and three 19-seaters, will fly the routes between the islands and each airport of the ABC islands will have two charging stations. The pool of electric aircraft will be able to handle 50% of the passenger demand of 2019.

The image below represents the total amount of electric aircraft flying between the island and the amount of charging station present at each airport.

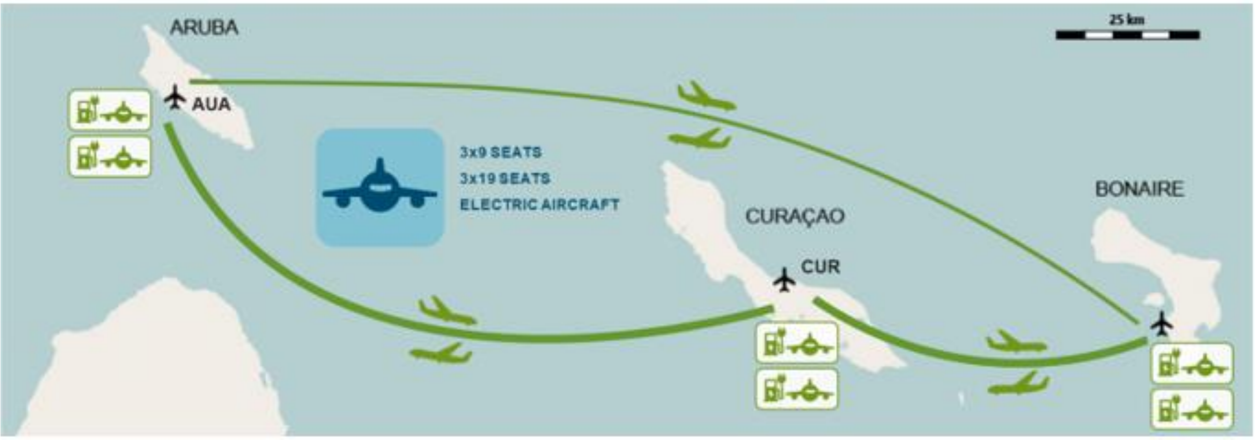


Figure 23:Overview of the pool of electric aircraft flying between the islands and the charging stations per airport

8.6.3 Phase 2035

In 2035, a total of twelve electric aircraft, six 9-seaters and six 19-seaters will fly the routes between the islands and each airport of the ABC islands will have four charging stations. During this phase, all the passenger demand of 2019 will be flown by electric aircraft.

The image below represents the total amount of electric aircraft flying between the island and the amount of charging station present at each airport.

Figure 24:Overview of the pool of electric aircraft flying between the islands and the charging stations per airport

8.7 Cost for the airport infrastructure

To determine the high-level cost required to invest in the new equipment at the airport for each phase, the airport of Bonaire was used as an example.

To assess the expected costs, the airport of Bonaire was used as an example. At the airport, platform 1-4 is used for regional flights, with 4 parking positions for both 9 or 19 seaters aircraft. To install the charging stations, it is assumed that the connection to the grid will have to upgraded to allow for higher power demand and earth works will be required to install new electricity cables. The existing stands will have to be refurbished to allow for a charging station to be placed on it.

This cost estimation does not include all the expected costs for the airport in terms of infrastructure. Some aspects were excluded in the study due to lack of information on requirements. For example, different or additional fire-fighting equipment are excluded, as no regulations is formulated on the matter at this point of time which makes a cost estimation impossible.

In addition, the phasing was used as a basis for determining the cost. The cumulative required infrastructure is given in the table below:

Table 10 - Overview of the cumulative requirements per phase

Cumulative requirements	Phase 1: 2026	Phase 2: 2030	Phase 3: 2035
Total # of aircraft simultaneously parked at the airport	One 9 seat aircraft	One 9-seat aircraft and a 19-seat aircraft	Two 9-seat and two 19-seat aircraft
Total # of charging station(s) required at the airport	1	2	4
Total power required per charging station	400kW	1x400kW and 1x900kW	2x400kW and 2x900kW

The cost overview includes costs for the infrastructure, the required works to install it and a risk factor.

The following infrastructure will have to be taken into account at the airport in order to accommodate an electric aircraft:

- Cables and connection to the island electricity grid including earth works,
- Stand refurbishment for the charging stations,
- Cost of a charging station (including rectifier and installation services),
- Power storage to buffer generated power to be able to handle the peak demands,
- Risk factor of 30% is taken from the total costs to reflect on the risk and complexity related to construction on the islands.

A high-level overview of the expected cost was made in the table on the right, the estimation is per phase. As the estimation is done without a specific design document, it can deviate with +/-50%.

Table 11 - Overview of the required additional infrastructure per phase and the costs

		Phase 1: 2026	Phase 2: 2030	Phase 3: 2035
Infrastructure requirements per phase	# of additional aircraft simultaneously parked at the airport	1x 9x	1x 19x	1x 9x 1x 19x
	# of additional charging station(s) required at the airport	1x	1x	2x
	Additional power required during peak periods	1x 400kW	1x 900kW	1x 400kW 1x 900kW

Related cost overview per phase (prices in €)	2026	2030	2035
Connection and installation with energy provider incl. cables and earth works	100,000	50,000	50,000
Stands refurbishment	100,000	100,000	200,000
Charging station incl. installation	350,000	800,000	1,150,000
Power storage station	50,000	100,000	150,000
Risk factor 30%[2]	200,000	350,000	500,000
Total (rounded up)	**1,000,000**	**1,500,000**	**2,200,000**

[1] Costs are in order of range +/- 50% and approximately the same for all 3 islands. They were estimated for Bonaire Airport as an example
[2] Risk factor of 30% is taken from the total costs to reflect on the risk and complexity related to construction on the islands

The pricing of the connection installation and charging station are based on information retrieved from previous projects conducted by RHDHV for the electric bus stations in Amsterdam and on the airport of Lelystad. The estimation of the earthworks and stand refurbishment were prepared using the unit prices of the Masterplan of Bonaire 2019 and the pricing of the Renovation of Main Apron Stands 3 and 4 for Aruba Airport.

8.8 Costs for the airline

A high-level cost analysis was done to give insight in the aircraft expenses for an airline. An overview is made of the aircraft procurement costs, maintenance costs and operating costs. These are compared to the costs of its fossil fuel counterpart that is currently in use at the islands. Furthermore, an estimation for the energy costs is given.

Note that for the electric aircraft, no procurement costs are published yet by the manufacturers. The data was based one estimations of alternative sources.

8.8.1 Cost comparison 9-seats aircraft

In Table 12 a comparison is given between an electric 9-seater (Eviation Alice) and the BN2A-Islander. The procurement cost for both aircraft is based on a newly bought plane.

Based on the information that is currently available, the initial investment of electric aircraft seems to be a bit higher than their fossil fuel counterpart. On the other hand, operating costs are promised to be much lower; it is expected that operating cost (energy and maintenance) will be 50-70% lower than a comparable fossil fuel counterpart [10].

Table 12 - Comparison between the electric Eviation Alice and BN2A-Islander, both 9-seats aircraft

	Eviation Alice	BN2A-Islander
Procurement cost	€ 3,500,000 [35]	€ 2,500,000 [36]
Maintenance cost (yearly)	Not available	Not available
Operating cost (hourly)	€ 175 [37]	€ 500[6]

8.8.2 Cost comparison 19-seats aircraft

In Table 13 a cost comparison is given between an electric 19-seater (Heart Aerospace ES-19) and the DHC-6 Twin Otter, its fuel-based counterpart.

Table 13 - Comparison between the electric Heart Aerospace ES-19 and DHC-6 Twin Otter, both 19-seats aircraft

	Heart Aerospace ES-19	DHC-6 Twin Otter
Procurement cost	€ 7,000,000 [38]	€ 6,200,000 [39]
Maintenance cost (yearly)	€ 130,000[7] [14]	€ 260,000 [40]
Operating cost (hourly)	Unknown, 50-70% lower [10]	€ 1,160 [41]

[6] Based on a source that considered a second hand BN2A-Islander
[7] Based on statement maintenance is 50% of equal size fuel plane at [48]

In Table 14 a comparison in costs is made between the Heart Aerospace ES-19 and the Beech 1900D. For the maintenance cost, no data was found.

Table 14 - Comparison between the electric Heart Aerospace ES-19 and Beech 1900D, both 19-seats aircraft

	Heart Aerospace ES-19	Beech 1900D
Procurement cost	€ 7,000,000 [38]	€ 3,500,000 [42]
Maintenance cost (yearly)	€ 130,000 [14]	Unknown
Operating cost (hourly)	Unknown, 50-70% lower [10]	€ 1,000 [43]

8.8.3 Battery replacement

Although the claimed 50-70% reduction in direct operating costs by Heart Aerospace incorporates replacement of the battery, it is worth mentioning the build-up of battery replacement costs.

The Heart Aerospace ES-19's battery should be able to handle at least a 1,000 cycles. With an average of 4 flights per day, this would mean that the battery would need to be replaced within one year. With an average price of $150/kWh [10], this would add up to $135,000 (€120,000) for a new 900 kWh battery.

8.8.4 Energy costs

If all 9- and 19-seater flights would be electric, the energy bill for Bonaire Airport would be € 686,000 in 2035.

Energy costs were estimated for Bonaire Airport based on the 2019 flight data for 9- and 19-seaters only. For each phase it was estimated what the energy costs would be if a share of the flights was to be executed by its electric counterparts. Rounded numbers are used. Underlying assumptions, based on Bonaire prices:

- Energy price remains constant at EUR 0.23/kWh[8] up to 2035
- 30 minutes charging time prior to departure
- A fixed monthly fee of EUR 8.23/kVA is used[9]
- Only 9- and 19-seater movements
- Elaborate calculations and energy pricing can be found in App II

Table 15 - Cumulative costs of energy per year

Phase 1 – three 9-seaters replaced by electric 9-seaters

- 2000 movements replaced (35% of total movements of 9 and 19 seaters) (2x Divi Divi Air, 1x EZ Air 9-seaters)
- 30 minutes 410 kW charging cycle prior to departure[10]

Total energy costs per year: €135,000

[8] *Based on energy price at Bonaire (source: webbonaire.com)*
[9] *Based on kVA fee at Bonaire (source: webbonaire.com)*
[10] *Conservative assumption as flight schedule is unknown*

Phase 2 – three electric 9-seaters from phase 1, added by three 19-seaters

- 2300 movements replaced (40% of total movements total movements of 9 and 19 seaters) (2x Divi Divi Air, 1x EZ Air 19-seaters)
- 30 minutes 900 kW charging cycle prior to departure
- Additional energy costs per year: € 327,000

Total energy costs per year: € 135,000 + € 327,000 = € 463,000

Phase 3 – three electric 9-seaters from phase 1, three 19-seaters from phase 2, added by three 9-seaters and three 19-seaters

- 1300 movements replaced (23% of total movements total movements of 9 and 19 seaters) (1x Divi Divi Air, 1x EZ Air 19-seaters)
- 30 minutes 900 kW charging cycle prior to departure
- Additional energy costs per year: € 223,000

Total energy costs per year: € 223,000 + € 463,000 = € 686,000

The energy costs are stated here as costs for the airport, as the airport is the customer of the energy supplier. However, in the future it could be very likely that fuel suppliers or energy suppliers will service the airlines directly. The mentioned energy costs could therefore be seen as 'fuel' costs for the airline.

9 Roadmap

9.1 How do we get to the first electric flight by 2026?

To achieve the implementation of electrification of aviation in the Netherlands by 2035 several steps will have to be taken.

In order to make the implementation possible within the desired timeline it is important to create a platform where stakeholders can be brought together and exchange information, needs and ideas. Ideally, this platform should be created and maintained by one or several of the players themselves. The grouping will serve as a tool to create a common vision, educate parties, align strategies and work out the step-by-step plan towards the implementation of electric flight.

Once the plan has been worked out for the specific situation, the stakeholders should come together on regular basis to discuss status, problem encountered and next steps. The existing initiatives in the Netherlands such as Power Up or DEAC area good examples of collaboration between different airports and collaboration between educational institutes and business and government. It is crucial to have all parties involved work close together in order to make the development possible.

Based on the analysis of the different stakeholders and the available technology in the coming 10 to 15 years, actions were defined and categorized per stakeholder.

In the next slides the actions can be found for each stakeholder. Subsequently, the actions are presented on a timeline running from today up to 2035, to provide insight on the timing of each action and the dependencies.

9.2 Stakeholder actions

The following actions were identified to make electric flying possible. This is done per stakeholder and a detailed version could be found in Appendix I. An overview is given in the diagram below, which summarizes the most important actions identified:

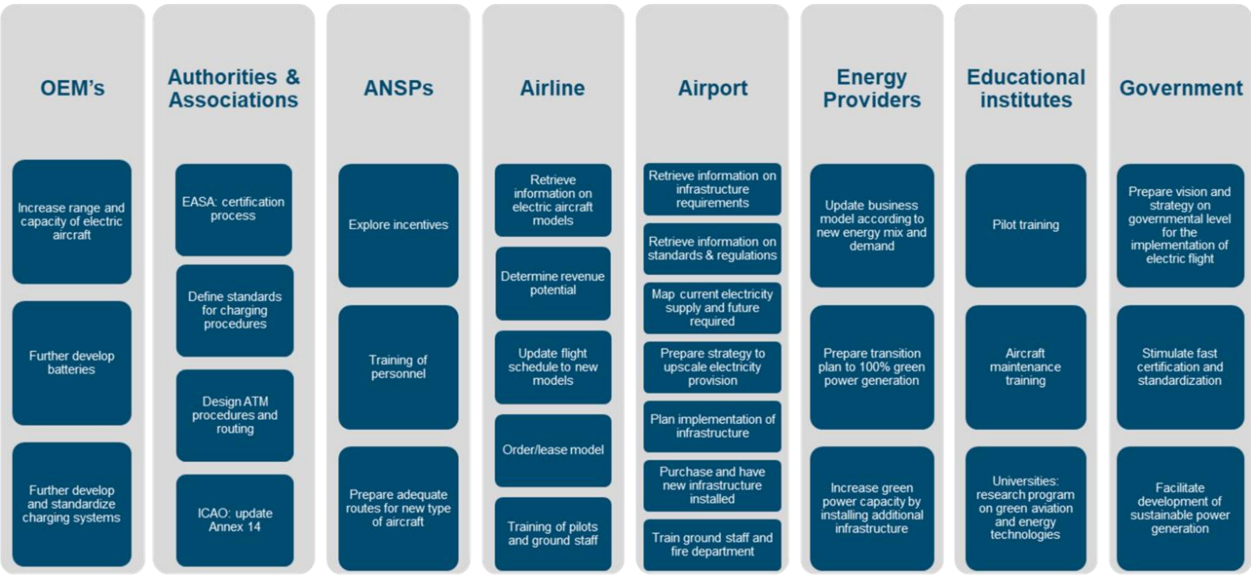


Figure 25:Overview of all the stakeholders and their identified actions

9.3 Roadmap to electric flying

The roadmap can be found in the following figure. All eight stakeholders are represented in different colors and their actions are set in time starting today and up to 2035.

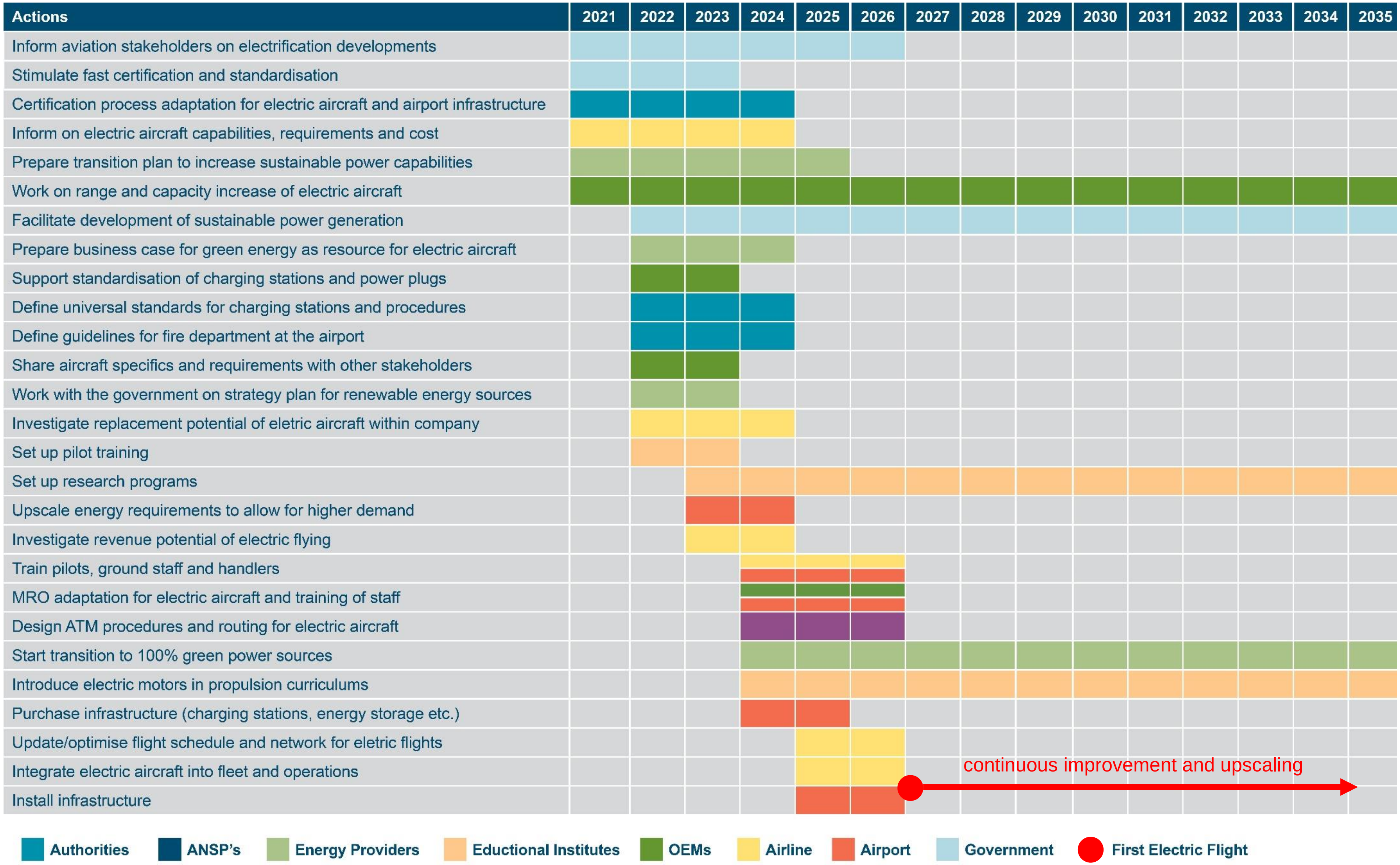
Important to note is that the actions of the different stakeholders run in parallel and several actions can only start once another action has been completed.

The first actions are mostly related on retrieving and sharing information between the stakeholders. Then, many stakeholders, such as the energy provider and the airlines will have to prepare a business plan and set up a plan for the transition.

When the planning has been set up, investing in the new models will be possible and the airport will have to aquire and install the infrastrcuture. This also means the airport wil have to scale up its energy provision by either installing renewable energy source(s) at the airport or by applying for a subscription at one the of the energy providers.

Once the first flight was made possible, a period of learning sets in, during this time the different stakeholder will gain knowledge on the new technology and give feedback to imporve the process.

Once the process is improved, additional electric aircraft can be introduced and the total pool of aircraft flying can be scalled up.


Actions
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
Inform aviation stakeholders on electrification developments
Stimulate fast certification and standardisation
Certification process adaptation for electric aircraft and airport infrastructure
Inform on electric aircraft capabilities, requirements and cost
Prepare transition plan to increase sustainable power capabilities
Work on range and capacity increase of electric aircraft
Facilitate development of sustainable power generation
Prepare business case for green energy as resource for electric aircraft
Support standardisation of charging stations and power plugs
Define universal standards for charging stations and procedures
Define guidelines for fire department at the airport
Share aircraft specifics and requirements with other stakeholders
Work with the government on strategy plan for renewable energy sources
Investigate replacement potential of eletric aircraft within company
Set up pilot training
Set up research programs
Upscale energy requirements to allow for higher demand
Investigate revenue potential of electric flying
Train pilots, ground staff and handlers
MRO adaptation for electric aircraft and training of staff
Design ATM procedures and routing for electric aircraft
Start transition to 100% green power sources
Introduce electric motors in propulsion curriculums
Purchase infrastructure (charging stations, energy storage etc.)
Update/optimise flight schedule and network for eletric flights
Integrate electric aircraft into fleet and operations
Install infrastructure
continuous improvement and upscaling
Authorities
ANSP's
Energy Providers
Eductional Institutes
OEMs
Airline
Airport
Government
First Electric Flight

10 Next steps and recommendations

This study gives insight into the required steps and investments to make the implementation of electric aviation possible. During the identification of actions and required infrastructure, it was identified that certain subjects have to be investigated before action can be taken. The following subjects require further investigation or development:

- Fire safety at the airport: the implementation of new propulsion will have an impact on the required fire safety equipment, infrastructure and training of personal. The impact of a battery fire on the airport has to be investigated first before conclusion can be frown on the requirements for fire safety.
- Flight scheduling to optimize peak power demand at the airport and battery life (timing & peaking): in order to optimise the life cycle of the batteries, it will be crucial that airlines together with ANSPs and airport prepare adapted flight schedules. In addition, to minimise the peak power requirements, airport will have to spread the arrival and departure of electric aircraft wisely.
- Encouragement to authorities (EASA) to renew airport safety and infrastructure requirements for electric flying: Finally, the airport will be depending on guidelines from the aviation authorities regarding the required infrastructure, the sizing of it and the adapted operations due to safety reasons. To prepare this update, research will be required to identify the impact of electric flying on safety and the differences in terms of safety when compared to aviation today.
- Business case: a business case will have to be prepared to determine the replacement by electric aircraft potential. This can be measured by comparing the investment cost and operational costs with the revenue potential of the (new) routes. The revenue potential could also include the increased positive impact on social aspects for example.
- Location of new infrastructure at the airport: the charging station location is evident, but the location of the power storage should be chosen such that distances are optimised to minimise energy loss.
- Supply or generation of power. In addition to the electric infrastructure, it should be investigated if the airport can choose to develop renewable energy sources on site from regulatory perspective. Technically, the location will also have to be assessed in order to, for example, avoid obstacle limitation, surfaces, glare due to reflection of the solar panels.
- Energy storage at/near the airport to absorb the peaks: the energy produced by the wind turbines will produce a certain amount of energy per day, nevertheless the energy demand will only occur 3-4 times a day at very large amounts. Therefore, it will be required to storage the energy in order to have enough during the peaks.
- Ownership, investment and operations of charging infrastructure. As the nature of the fuel to be provided to the aircraft will change, it is required to investigate and determine who will provide the energy to whom and who will be responsible for the handling of the charging procedures at the airport.

11 Bibliography

[1] Ministerie van IenW, „Verantwoord vliegen naar 2050 - Luchtvaartnota 2020-2050," Ministerie van IenW, Den Haag, 2020.

[2] „Ontwerp Actieprogramma Hybride Elektrisch Vliegen (AHEV)," 2019.

[3] „DEAC," [Online]. Available: https://deac-teuge.nl/over/. [Geopend 2021].

[4] „Stichting Duurzaam Vliegen," 2018. [Online]. Available: https://duurzaam-vliegen.nl/platform-duurzaam-vliegen/. [Geopend 2021].

[5] „Fundashon Mariadal," 2020. [Online]. Available: https://www.fundashonmariadal.com/over-ons/. [Geopend 2021].

[6] „Aruba Airport," 2021. [Online]. Available: https://www.airportaruba.com/press-releases/cooperation-agreement-dcca. [Geopend 2021].

[7] EASA, „Aircraft certification," 18 11 2021. [Online]. Available: https://www.easa.europa.eu/domains/aircraft-products/aircraft-certification.

[8] G. NL, „Safety Aviation," Government of the Netherlands, [Online]. Available: https://www.government.nl/topics/aviation/safety. [Geopend 8 11 2021].

[9] S. 3. JU, „SESAR 3 Joint Undertaking," SESAR JU, 2021. [Online]. Available: https://www.sesarju.eu/. [Geopend 18 11 2021].

[10] Heart Aerospace, „Heart Aerospace FAQ," Heart Aerospace, 2021. [Online]. Available: https://heartaerospace.com/faq/. [Geopend 2021].

[11] Business Insider, „Business Insider," 6 2021. [Online]. Available: https://www.businessinsider.nl/elektriciteitsnet-nederland-overbelast-liander/. [Geopend 11 2021].

[12] Roland Berger, „Aircraft Electrical Propulsion - The Next Chapter of Aviation?," Roland Berger LTD, London, 2017.

[13] Lilium, „Lilium Jet," Lilium, 2021. [Online]. Available: https://lilium.com/jet. [Geopend 2021].

[14] „Heartaerospace," 2021. [Online]. Available: https://heartaerospace.com/faq/ .

[15] Embraer, „Embraer Energia," Ambraer, Nov 2021. [Online]. Available: https://embraercommercialaviationsustainability.com/concepts/#energia. [Geopend Nov 2021].

[16] Wright Electric, „Wright Electric," Wright Electric, 2021. [Online]. Available: https://www.weflywright.com/. [Geopend November 2021].

[17] Science Direct, „Lithium Ion Battery," [Online]. Available: https://www.sciencedirect.com/topics/chemistry/lithium-ion-battery. [Geopend 2021].

[18] H. e. al., „Ce-Liner Case Study for eMobility in Air Transportation," 2013.

[19] S. &. Z. X. &. K. K. Sahoo, „A Review of Concepts, Benefits, and Challenges for Future Electrical Propulsion-Based Aircraft. Aerospace," 2020.

[20] K. Chau, „Pure electric vehicles," *Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance,* 2014.

[21] L. Trainelli, „Evaluating the impact of fleet switching to hybrid-electric aircraft on airport infrastuctures," in *Aerospace Europe Conference 2020*, Milan, 2020.

[22] F. Salucci, „Optimal recharging infrastructure sizing and operations for a regional airport," in *Aerospace Europe Conference*, Milan, 2020.

[23] ABB, „Terra HP Charger – Up to 350 kW," ABB, 2021. [Online]. Available: https://new.abb.com/ev-charging/produkte/car-charging/high-power-charging. [Geopend October 2021].

[24] M. Kane, „Industry Develops 3.75 MW Charging System For EV Trucks,” Inside EVs, 27 Sept 2021. [Online]. Available: https://insideevs.com/news/535918/megawatt-charging-system-ev-trucks. [Geopend 18 Nov 2021].

[25] Aruba Airport, 2019.

[26] „DC-ANSP,” 2021. [Online]. Available: http://dc-ansp.org/.

[27] „ANSA,” 2021. [Online]. Available: https://ansa.aw.

[28] „webaruba,” september 2021. [Online]. Available: https://webaruba.com/energy-production/power-production-figures .

[29] „webaruba.,” september 2021. [Online]. Available: https://webaruba.com/energy-production/power-production-figures.

[30] „webbonaire,” 2021. [Online]. Available: https://www.webbonaire.com/en/green-power/ .

[31] „Aqualectra,” september 2021. [Online]. Available: https://www.aqualectra.com/.

[32] „Curacaovakantieland,” 2021. [Online]. Available: https://www.curacaovakantieland.nl/thema-artikelen-over-curacao-curacao-vakantieland/windenergie-curacao-curacao-vakantieland/.

[33] D. M. o. I. a. Water, Interviewee, [Interview]. 2021.

[34] „Nexus case Bonaire Factsheet 5 Energy,” Wageningen University and Research, Wageningen, 2019.

[35] „Business Insider,” 2021. [Online]. Available: Online: https://www.businessinsider.com/inside-alice-first-full-size-passenger-electric-plane-eviation-2020-10?international=true&r=US&IR=T . [Geopend September 2021].

[36] „Skytamer (based on BN-2T estimates),” [Online]. Available: https://www.skytamer.com/Britten-Norman_BN-2A-2.html - . [Geopend November 2021].

[37] „Clean Technica,” [Online]. Available: https://cleantechnica.com/2021/07/17/eviation-rolls-out-100-electric-airplane-alices-production-version/ . [Geopend November 2021].

[38] „Britten-norman,” [Online]. Available: https://britten-norman.com/app/uploads/2021/04/1974-BN2A-26-Islander-Specification-Jan-2021.pdf . [Geopend Novembre 2021].

[39] „Bjtonline,” [Online]. Available: https://www.bjtonline.com/aircraft/viking-air-dhc-6-400-twin-otter . [Geopend October 2021].

[40] „Vikingair,” [Online]. Available: https://www.vikingair.com/new-vs-used-nn. [Geopend October 2021].

[41] „aircraftcostcalculator,” [Online]. Available: https://www.aircraftcostcalculator.com/AircraftOperatingCosts/510/Viking+Air-DeHavilland+6-300+Twin+Otter#:~:text=Based%20on%20450%20annual%20owner,down%20to%20%241%2C324.28%20per%20hour. . [Geopend November 2021].

[42] [Online]. Available: https://aerocorner.com/aircraft/beechcraft-1900/ . [Geopend October 2021].

[43] „planesfordummies,” [Online]. Available: http://planesfordummies.com/manufacturer/operating_cost/BEECH/1900D/8. [Geopend November 2021].

[44] M. G. J. S. A. &. C. V. Cames, „Emission Reduction Targets for International Aviation and Shipping,” ÖkoInstitut. Brussels: European Parliament, Policy Department A: Economic and Scientific Policy, Brussels, 2015.

[45] „Meteo,” September 2021. [Online]. Available: https://www.meteo.cw/climate.php.

[46] „D-point,” 2021. [Online]. Available: source: https://www.d-point.net/pdf .

[47] „Ainonline,” 2021. [Online]. Available: https://www.ainonline.com/aviation-news/air-transport/2021-03-11/wideroe-goes-electric-tecnams-p-volt .

Appendix

A1 List of abbreviations

Abbreviation	Meaning
ACI	Airports Council International
AHEV	Actieprogramma Hybride Elektrisch Vliegen
ANSA	Air Navigation Services Aruba
ANSP	Air Navigation Service Provider
ASTM	American Society for Testing and Materials
ATS	Air Traffic Services
BSS	Battery Swapping Systems
CAA	Civil Aviation Authority
CCAA	Civil Aviation Authority Aruba
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
DCCA	Dutch Caribbean Cooperation of Airports
DEAC	Dutch Electric Aviation Centre
EASA	European Union Aviation Safety Agency
EIS	Entry Into Service
EUROCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
ICAO	International Civil Aviation Organization

IenW	the Ministry of infrastructure and Water
KLM	Royal Dutch Airlines
MCS	Megawatt Charging Systems
MRO	Maintenance Repair and Overhaul
OEM	Original Equipment Manufacturer
PSO	Public Service Obligation
R&D	Research and Development
RAM	Regional air mobility
RHDHV	Royal HaskoningDHV
SAE	Aerospace industry standards
SESAR	Single European Sky Air Traffic Management Research
SoC	State of Charge
UAM	Urban Air Mobility
VFR	Visual Flight Rules
VTOL	Vertical Take-Off and Landing

A2 Stakeholder interviews

The stakeholders to be interviewed were selected together with the Ministry of infrastructure and Water (IenW). The following stakeholders were interviewed:

Manufacturers:

- Pipistrel
- Heart Aerospace
- Ampaire
- Zeroavia

Authorities & Associations

- CAA Aruba
- CAA Curaçao

ANSP:

- AVINOR

Airline:

- KLM
- Winair

Airport operators

- Bonaire airport
- Aruba airport
- AVINOR
- Power – Up (Initiative of Dutch airports)

Energy providers:

- Ministry of infrastructure of Curaçao

Government:

- IenW
- Ministry of Economic development of Curaçao
- Ministry of infrastructure of Curaçao