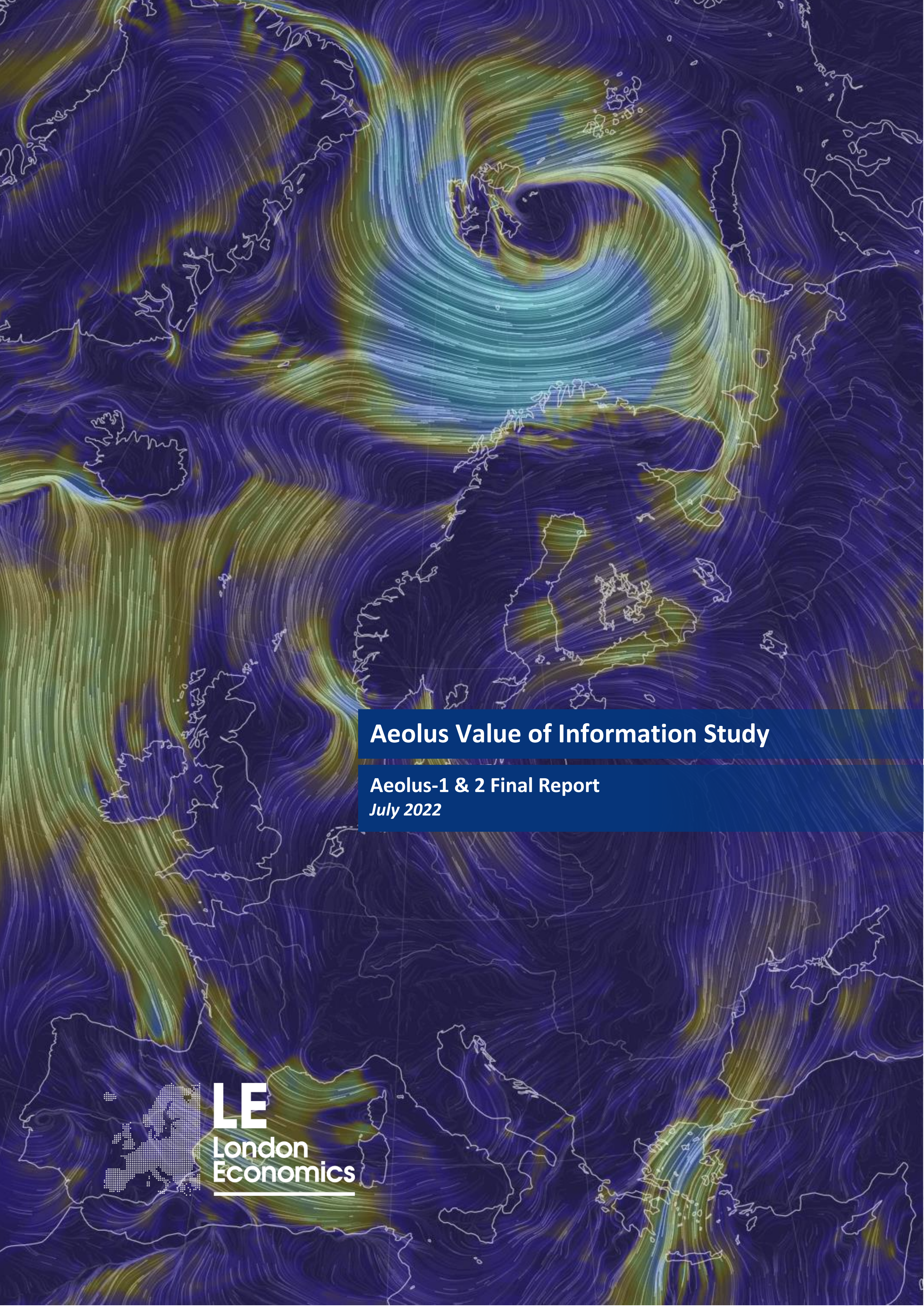

Aeolus Value of Information Study

Aeolus-1 & 2 Final Report

July 2022

London Economics

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w: londoneconomics.co.uk e: info@londoneconomics.co.uk : @LE_Aerospace
t: +44 (0)20 3701 7700 f: +44 (0)20 3701 7701

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Authors

Romain Esteve Senior Economic Consultant
Sabah Mohammed Economic Analyst
Rasmus Flytkjaer Divisional Director
Dr Ashwini Natraj Associate Director
Cera Kenny Intern
Patrick Mathewson Economic Consultant

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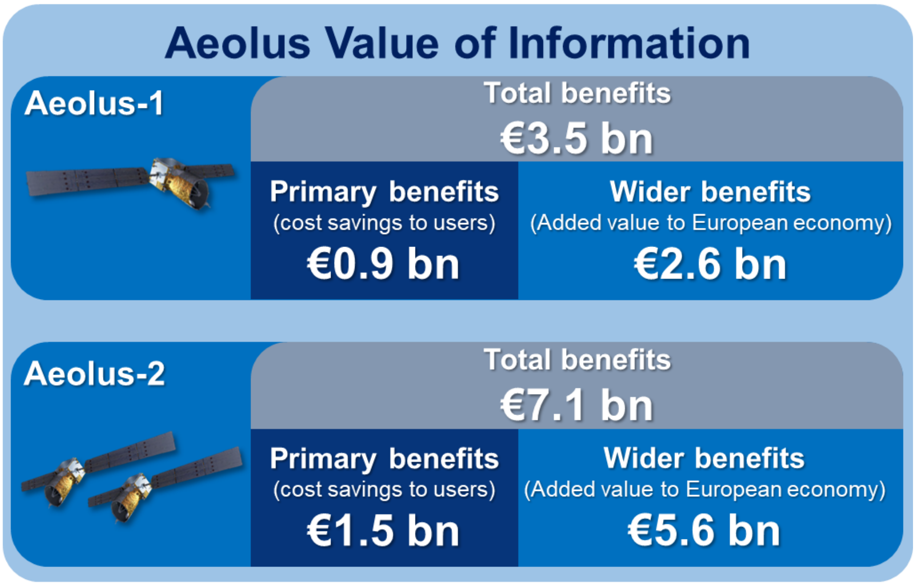
Executive Summary

Box 1 Key Findings

- The study finds that the total benefits of Aeolus-1 data and information to European stakeholders and society amounts to **€3.5Bn** over its lifetime, greatly **exceeding the mission costs**. Aeolus-2 could generate **€7.1Bn** over the expected designed lifetime.
- Mission costs are estimated at €480m for Aeolus-1 and €1,105m for Aeolus-2
- The average willingness to pay (WTP) for Aeolus data and information across the sample of European decision makers consulted is **€60,000 per year**.
- The study highlights the **critical importance of open data policy** in Europe. Users of Aeolus-1 data save up to **€240 million** per year in primary benefits from accessing free data which represent a cumulative value of **€0.9 billion cost savings to users** over the missions' lifetime. The WTP experiment shows that under a different policy, prices would likely be prohibitively expensive for most smaller organisations. **Open data policy reduces barriers to adoption in this case**.
- The Aeolus-1 mission has a very large single-mission impact on Numerical Weather Prediction (NWP) and related benefits for European society. Aeolus-1 data represent **less than 1% of data inputs** in NWP models, and investments in the Aeolus programme led to an **improvement of numerical weather predictions of 4%** contributing an additional **€2.6 billion to European GDP over the lifetime of Aeolus-1**.
- Building on the success of the demonstrator, Aeolus-2 contribution to the wider European GDP could reach **€5.6 billion** over its lifetime.
- Individuals who **self-identify as knowledgeable** of the wider benefits (strategic, catalytic and technological) of Aeolus have a WTP **44%** higher than those with lesser knowledge.
- Insights from Aeolus have the potential to support **European independence in energy production.**
- The wind energy and insurance sectors are likely to drive the uptake of Aeolus-2 data and information.
- The success of the present pilot study suggests that **Value of Information is a suitable research framework** to analyse the socio-economic benefits of EO platforms and programmes

Case studies



Case Study 1: Aeolus-1 Satellite

Willingness-to-Pay Results

The average willingness to pay (WTP) among respondents is equal to **€60,000 per year**.

- **Within segments:** Results show there is substantial variance between segments. National Met Offices and Climate science and research centres have the highest average WTP averaging at **€87,300 and €30,000 per year** respectively. Segments further down the value chain exhibit a smaller WTP (aviation: €21,000 per year; energy: €2,400 per year).
- **Experience with using Aeolus-1 data:** Results show the Met Office segment had the highest number of organisations with direct experience with using the data and that the average WTP of **organisations using the data is 44% higher than those not using the data**.
- **Open data policy:** Free and open data access reduces the barriers to adoption of data and therefore increases user uptake. Without such policy, budget constraints would prevent the Value of Information to trickle down the value chain of the European economy.
- **Organisation Size:** The results shows that organisations with a budget below €5 million have a WTP of €16,000 on average per year, whilst organisations with a budget above €5 million have a WTP over **5 times greater** roughly equal to **€85,000 per year**.
- **Awareness of Wider Benefits (Catalytic, Strategic & Technological)[1]:** The results suggest that respondents who self-identify as having complete awareness of the satellite's benefits exhibit a WTP **44%** greater than others. Respondents with **complete awareness** of the wider benefits have a WTP of €73,300, whilst those with **partial awareness** have a WTP of €50,600. In this context, complete awareness constitutes individuals who **self-identify as knowledgeable** of the wider benefits of Aeolus.

[1] Catalytic benefits capture the value associated with wider benefits and impact on decision making of third-party organisations. Technological benefits are generated using a new technology in adjacent segments. For instance, ground-based lasers inspired from Aeolus technology are being developed to validate data captured by the satellite. In the future, this may support collection of additional high-accuracy wind and atmospheric data at local scale. Strategic benefits refer to the benefits of having access to a unique set of data and information. This provides unique knowledge impacting strategic positioning and strengthening European space competitiveness.

Assessment of Socioeconomic Benefits of Aeolus-1

Primary Benefits: These primary benefits focus on the primary segment organisations and users which directly work with assimilating the observations into NWP models and relying on forecasting services for research and operations. To account for users of the data, it is assumed that the 4000 users from EUMETSAT benefit from free access to this data.[2] Scaling the individual average WTP result of €60,000 from this study to the user level, the benefits of Aeolus-1 data amount to **€240 million per annum**.[3] Over the operational lifetime of the mission (3.5 years), these **benefits accumulate to approximately €900 million for 4000 users**, in real terms.

Wider Benefits: Whilst representing less than 1% of data inputs, Aeolus-1 **improves wind measurement and NWP forecasting accuracy by 4%.** Weather sensitive GDP in ESA Member States and Cooperating States amounts to €7.2 trillion annually. Assuming weather forecasting information has an impact on overall GDP of 0.25%, Aeolus-1 yields benefits of **€0.7 billion per year**.[4] Over the **3.5 years operational lifetime,** this amounts to **€2.6 billion** in real terms.

Case Study 2: Aeolus-2 Satellite

In the case of Aeolus-2, the average WTP among respondents is equal to **€62,000 per year**. Met Offices exhibit the highest WTP value of **€86,200 per year**. Organisations with a larger budget (in excess of €5 million) had an average WTP **seven times greater** than organisations with a smaller budget.

Primary Benefits: Benefits of Aeolus-2 data amount to **€248 million per annum**. Over the targeted operational lifetime of the mission (10 years), these benefits accumulate to approximately **€1.5 billion** for 4000 users, in real terms.

Wider Benefits: Assuming weather forecasting information has an impact on overall GDP of 0.25%, the **conservative scenario** suggests that Aeolus-2 yields wider benefits of **€0.6 billion** in 2030. Over the 10-year operational lifetime, this amounts to **€5.6 billion** (in real terms).

Benefits of Open Data Policy

A substantial proportion of respondents highlighted that data from Aeolus should be provided for free. From follow-on consultations, it was evident that smaller organisations benefit greatly from being able to access the data for free due to their stricter budget constraints. Meanwhile, larger organisations highlighted the benefits of knowledge sharing where organisations freely share and exchange data from different satellites globally. This includes exchanging data from Aeolus with observations from Indian, Chinese and US satellites and was perceived as the "best commercial model possible".

[2] To date, the number of users of Aeolus-1 data is difficult to estimate. Further analysis of the user base would enable to refine the results of this first pilot study.
[3] This follows a simplifying assumption of homogeneity across the 4000 users.
[4] 0.25% impact on overall GDP mirrors the assumptions in the 2014 EUMETSAT study "The case for EPS/Metop Second-Generation: cost benefit analysis", pp. 13. Available at: https://www.eumetsat.int/media/16881

1 Introduction

This report presents the value of information (VOI) framework, methodological approach and results of the present pilot study which aimed to assess the value generated by the Aeolus-1 and 2 satellite missions undertaken by London Economics for the European Space Agency.

1.1 Objectives of the Study

The aim of this study is to assess the value generated by the demonstration mission Aeolus-1 and the follow-on operational mission Aeolus-2. This study is a **pilot** which also strives to demonstrate the utility of new socio-economic frameworks, in particular the Value of Information (VOI) framework.

The **value of information framework** (VOI) **directly measures the amount that decision makers are willing to pay** to access data or information to make better informed decisions. This amount depends on how uncertain decision makers are prior to accessing the additional information, the cost of accessing the additional information and the outcome that is at stake.

Key Objectives:

- To quantify the current and prospective benefits, as well as the value generated by both the Aeolus-1 and Aeolus-2 satellites.
- To examine the wider benefits (including catalytic, strategic, and technology benefits) of Aeolus-1 and -2 satellites.
- To apply the value of information framework to European decision makers across four segments (Meteorology, Climate Science, Aviation, and Energy); and
- To complement existing socio-economic impact studies in the Earth Observation (EO) sector.

1.2 Scope of the Study

A key objective of this pilot study is to value the benefits of Aeolus to **European decision makers**. Hence, the survey was sent to European organisations from 28 countries and Supranational Organisations. The study covered the full list of ESA Member States, Associate Members, and PECS countries.

Given the ubiquity of weather data in decision-making amongst public institutions, one key activity was to down select the primary market segments that the present pilot study could cover. The following recommendations were a product of accumulated firm experience at London Economics and desk-based research. In addition to the expertise of our Space Team, our Behavioural Economics Team has advised governments and European agencies for over 15 years and completed a multitude of VOI and WTP experiments. We have also established a strong position in weather related socio-economic studies. The initial selection covered segments most affected by weather variation and those in which wind data could be beneficial.

- Meteorological services
- Agriculture
- Forestry
- Climate science

- Construction
- Disaster preparedness and resilience
- Energy and water (incl. renewable energy)
- Health
- Transports & logistics (Maritime, Aviation, Rail, Road)
- Mining & Quarrying
- Oil & Gas
- Tourism

Four segments were selected by prioritising those sectors in which the relative size of economic, environmental, and social impacts is likely to be the most affected. The selected **four priority segments** are Meteorological Organisations (Met Offices), Climate Science and Research, Energy (incl. renewable), and Aviation.

Over 250 contacts were gathered for each segment and in each country representing over 100 European organisations.

1.3 Work Package Structure and Descriptions

The approach to this study consisted of six core Work Packages (WPs), detailed as follows:

WP0 – Project management

This work package consisted of a presentation of key scope and approach discussion points, required Agency inputs and Project Management (PM) essentials to initiate the project at the Kick-Off Meeting (KOM). The KOM was used to finalise the project scope, all aspects of the methodology, available data, format and content of deliverables, timeline, and project management essentials.

WP1 – Background theory

This work package comprised of a comprehensive literature review which aimed to summarise existing literature about the value of information (VOI) framework and provide evidence of VOI methods applied to earth observation (EO) missions, data and information. Having reviewed over 80 papers, the contingent valuation (CV) methodology was selected as the most appropriate approach to valuing the Aeolus satellite missions.

WP2 – Methodology Outline

This work package involved designing a survey with a CV approach to assess organisations' willingness to pay (WTP) to access data from Aeolus-1 and the follow-on Aeolus-2 satellite mission. The survey also aimed to assess the wider benefits (catalytic, technological, and strategic) of the satellite mission quantitatively and qualitatively. This work package also included the identification of decision makers from European organisations and supranational organisations. As detailed user information is not currently publicly available, a key focus of this work package was to generate a representative sample of these users. This sample was generated based on intensity of Aeolus data use (Aeolus value chain) and stratified by country, organisation type, use case, and weather information value chain segment. Stakeholders were identified from the full list of ESA Member States, associate members and PECS countries.

WP3 – Data collection and analysis

The data collection stage was carried out through an online survey using Smart Survey. A schedule with clear milestones was established to ensure a high response rate. To maximise the response rate, the number of responses received at each milestone were closely monitored and stakeholders who had not completed the survey were chased. Stakeholders were routinely reminded to answer the survey. Additional consultations where respondents expressed an interest in learning further about the study and sharing further motivation behind their responses were also carried out.

The survey and experiment data were analysed using established statistical methods mainly through the use of the software R. The first step in the data analysis involved undertaking a frequency analysis, which shows the distribution of responses to all questions (using the full response ranges and exact wording). This also provided an analysis of the response rates to each individual question. The aim of this part of the data analysis was to ensure a high level of transparency in the analysis and that the responses are well documented. In addition, this step allowed us to analyse whether the sample was representative and helped us to obtain some initial conclusions from the data collected. An analysis was also carried out on the different average WTP responses received based on organisation type, budget and size. The organisation level data was then scaled up to provide quantitative estimates of the benefits of the satellite mission to European GDP. An assessment of the wider benefits of the satellite missions was also considered in the analysis as respondents were asked about the importance of the technological, catalytic and strategic benefits of the missions.

WP4 – Case studies

Two case studies capturing the main findings of the survey results and data analysis were created. Both case studies presented the range of potential activities of the satellites and provided an insight to the calculation of the value of information to decision makers. The first case study covered the observed VOI of decision makers, taking as inputs the current information provided by Aeolus-1. The second case study covered the prospective mission of Aeolus-2 and provided insights of the expected VOI, forecasted into the future.

WP5 – Report writing

The final deliverable involves this final report which presents the survey results and main conclusions from this pilot study. It also includes the two infographics detailing the key findings on each of the two satellite missions.

1.4 Caveats and Limitations

To date, the number of users of Aeolus-1 data is difficult to estimate. The survey highlights that only a handful of organisations are direct users of the data. But some organisations might be utilising the information without being fully aware of it by using the information provided by NWP models (e.g., organisations receiving weather information from Met Offices integrating Aeolus data in their models). Further analysis of the user base would enable the refinement of the results of this first pilot study.

Respondents from the aviation and energy segment showed greater dropout rates early in the survey, suggesting that the survey design was not necessarily fitted for them or there was an issue in the identification. Additionally, a few responses from organisations within these segments stated that the satellite data is not valuable to them. This could potentially be due to the lack of knowledge regarding the satellite and its unique provision of global wind data, resulting from benefits within these segments which are more indirect. This illustrates that there may be a need for wider demonstration across European organisations of potential improvements from Aeolus to NWP models and the impact it has on day-to-day operations in different industries.

Furthermore, respondents were not always aware of spending decisions within their organisation and how their organisations' budget is allocated. Some respondents worked in technical roles, hence they found it difficult place a value on the data. This was evident during the follow-on consultations with respondents who stated they understood the importance of the data but were unable to quantify its value. This highlights a problem with the identification process of selecting respondents. Some organisations had limited contact details available of potential stakeholders, therefore making it difficult to accurately select the individual who was best able to respond to the survey.

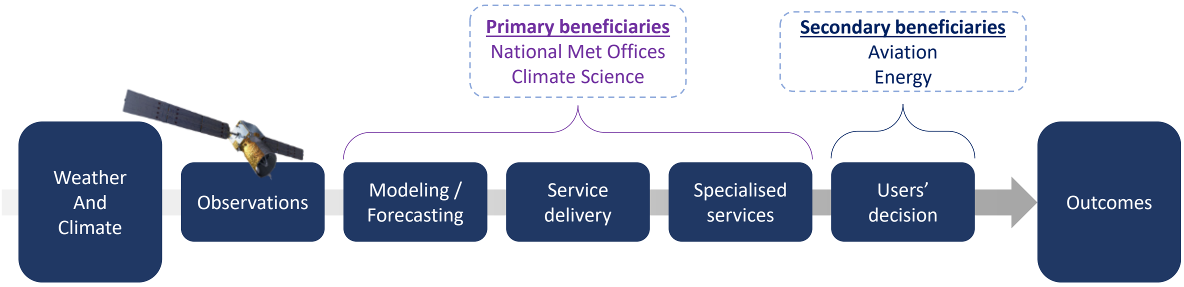
This pilot study would have benefitted from improved prior knowledge of spending on data and subscriptions by different types of organisations. This information would have helped to calibrate the WTP values presented to respondents. The selected values were based on ECMWF pricing, however future studies should also consider the organisations' spending more broadly.

The results of the survey included 12 protest responses which represented 30% of the results. Protest responses are commonly encountered when using a contingent valuation approach in a survey and involve respondents refusing to state a value, hence providing a WTP value of €0. This valuation may occur if respondents do not value the commodity, if they object to the principle of placing a monetary value on the commodity, or they may feel strongly that the responsibility for provision falls on another actor such as the Government. Whilst all questions stated that the valuations were not part of a pricing exercise, the framing of the questions may not have been suitable for all respondents.

2 Value Chain

To identify and monetise the benefit streams, the study uses the weather value chain presented in Figure 1. This value chain distinguishes and captures two streams of benefits. The **primary benefits** are generated through the access to improved, free observations, that yield a surplus in users' balance. This surplus is measured by observing the willingness to pay of users for data or services. These same data is then used to generate numerical weather prediction (NWP) models affecting the day-to-day operations of a multitude of segments and stakeholders.

Figure 1 Value Chain



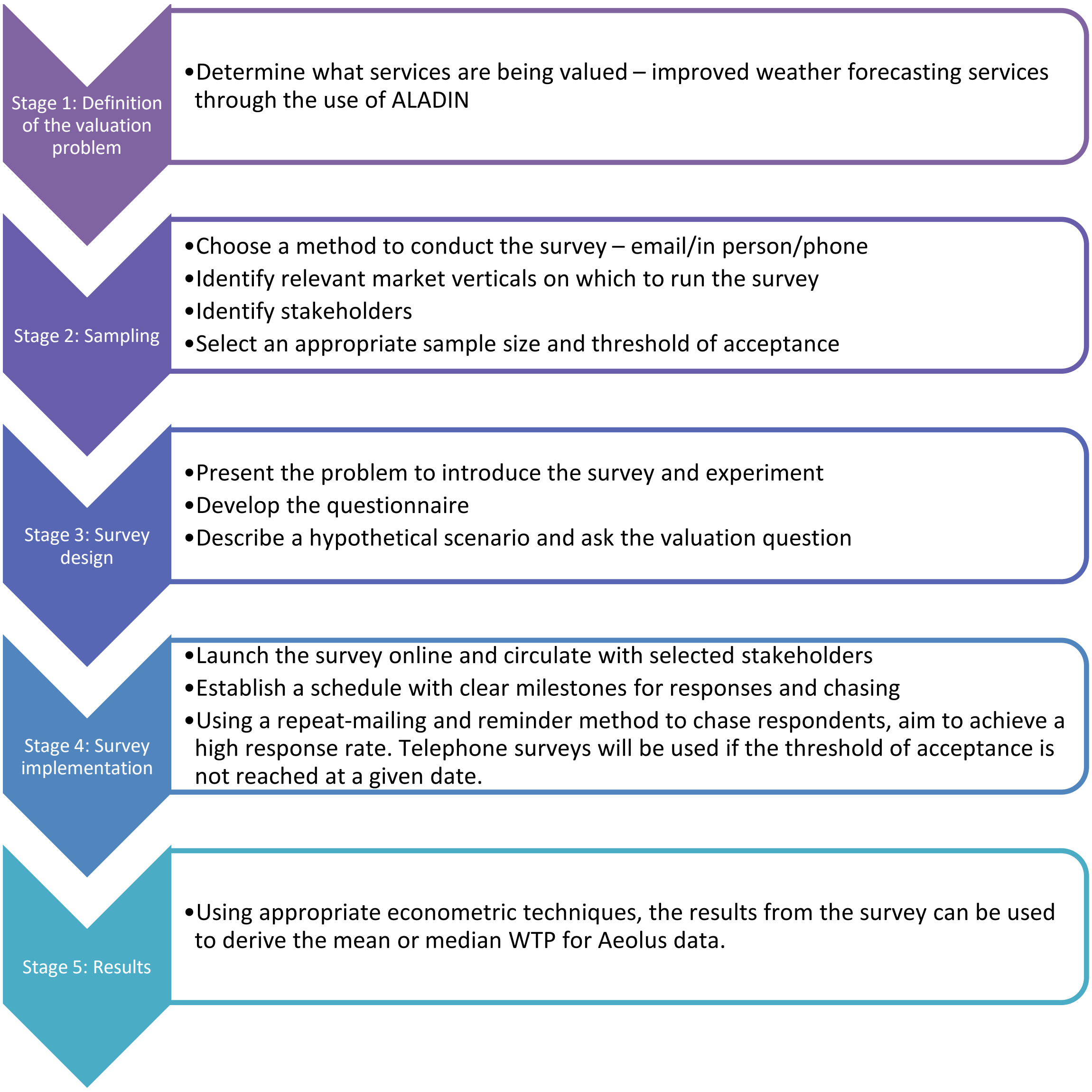
Note: The value chain only includes the sectors that are in scope of this study
Source: London Economics analysis

NWP forecasts are distributed for free to industries and the population, affecting the decision making of stakeholders. The industrial and catalytic benefits constitute a **wider stream of wider benefits**. For example, industries such as the aviation sector strongly rely on forecasting to assess the safety and feasibility of flights and predict any potential weather-related delays in advance to minimise any impacts on costs. In the Energy sector, advanced weather information helps to forecast any potential changes in energy supply and demand, particularly in wind energy where wind speed readings from Aeolus could help provide organisations with key information about the expected capacity of the supply.

3 Methodology and Survey Design

The methodological approach to this study has been designed to assess the value of information provided by Aeolus. This design is informed by the extensive literature review conducted as part of WP1. This section discusses the selected methodology, the rationale behind this selection, and detail the survey circulated to the relevant stakeholders.

Figure 2 High-Level Approach



3.1 Contingent Valuation method

Whilst several different frameworks to measure the VOI exist, the method selected considering the objectives of this study is the contingent valuation (CV) approach. Following the extensive literature review conducted in WP1, the CV method was found to be most widely used to value non-market goods, including Earth Observation data and weather information services. Over 2,000 studies have previously used the CV approach on a wide range of subjects over the last 30 years. This method has been identified as the most appropriate method for evaluating the benefits from having Earth Observation data. Moreover, the CV method was formally recognised as the method to use to value public weather services in Great Britain by Teske and Robinson (1994) and Chapman (1992) in the United States. This method has also been used to influence policymaking by organisations including the World Bank and US Agency for International Development (USAID).

The CV method is a stated preference technique which relies on the creation of a hypothetical market and involves using a survey to directly ask respondents how much they would be willing to pay (or accept) to access weather information and Earth Observations provided by the Aeolus satellite. To meet the objectives of the study, the contingent valuation survey was embedded in a survey to capture the wider benefits of the Aeolus satellite mission including the political, scientific, and catalytic benefits.

The ability of the CV approach to capture the wider socioeconomic benefits of the satellite mission makes it a favourable method to use when compared to approaches such as cost-benefit analysis, which focus entirely on quantifiable impacts. Whilst the choice modelling approach for this study was initially considered, following the work in WP1, the contingent valuation approach was selected for following reasons:

- The CV method is more easily navigated and comprehended by respondents which limits the number of random response errors.
  - Respondents are not required to spend a long time answering the survey, which should result in a high response rate, yet useful and sufficient information can still be extracted from the responses
- Following consultations with ECMWF and EUMETSAT, objectives of capturing wider benefits of the Aeolus satellite (strategic, catalytic, reputational, etc.) were prioritised.
- CV is a simple method to set up and is easily scalable and replicable as the randomisation of questionnaires and WTP options is only applied on one variable – the price. The remaining characteristics of the product or service to be valued remain constant.
- CV is the most used method in EO-related studies. As this study targets EO missions (with scope for replicability) it seems appropriate to use CV rather than CE which seems more adapted to valuing specific services. There is strong evidence in the literature that the contingent valuation method can elicit the WTP for EO data and services with a high degree of confidence.
- Results from the CV survey can be scaled to assess the potential benefits (at user level). CE results are more meaningful when looking at marginal gain

Contingent Valuation questions can be presented to respondents in different forms, which have been summarised in Table 1. The chosen format for this study is the Double-Bounded Dichotomous Choice, and rationale for this is provided in section 3.1.1.

Table 1 Contingent Valuation question forms

Question Format	Description	Advantages	Concerns
Open-Ended	Respondents are asked to state their WTP	■ Simple to implement ■ Easy for respondents to understand	■ High probability of receiving many 'zero' responses ■ Clustering around 'rounded' figures (€100, €20, etc…) ■ Risk of high number of 'protest' bids
Double-Bounded Dichotomous Choice	Respondents are presented with a value and asked whether they are willing to pay that value. If respondents accept, they are presented with higher offers and asked if they are willing to pay. If an offer is rejected, respondents are presented with lower offers. WTP can be calculated from the highest offer that the respondent is willing to pay	■ Simple to design and implement ■ Easy for respondents to understand ■ Can be appropriately designed to provide more precise WTP estimates	■ Opportunity for strategic behaviour. If respondents know that offers increase every time they accept, they may reject an offer even if they would otherwise accept ■ WTP is affected by the initial offer and increments of increases in offers ■ Large sample size required as there is little information per respondent ■ Provides a range of estimates rather than a point estimate
Bidding Game	Respondents are presented with offers and asked whether they accept/reject. With every offer that is accepted, respondents are given higher offers.	■ Easy for respondents to understand	■ WTP is affected by the initial offer and increments of increases in offers
Payment Card Method	Respondents are presented with the full range of responses. WTP is inferred by the maximum amount they indicate on the card.	■ Less opportunity for respondents to provide strategic responses than double-bounded dichotomous choice method ■ Lower sample size required compared to the double-bounded dichotomous choice method	■ Respondents potentially provide responses which are biased to the centre of the range ■ Responses are based on the range of the card ■ Provides a range of estimates rather than a point estimate ■ Respondents may provide lower estimates than their actual WTP

Sources: London Economics review of: Accent; RAND Europe. (2010). Review of stated preference and willingness to pay methods. Competition Commission; Pearce, D., & Ozdemiroglu, E. (2002). Economics valuation with stated preference techniques. Rotherham: Department for Transport, Local Government and the Regions; Bateman, I., Carson, R., Day, B., Hanemann, M., Hanley, N., Hett, T., et al. (2002). Economic valuation with stated preference techniques: A manual. Cheltenham: Edward Elgar.

3.1.1 Double Bounded Dichotomous Choice

For this study, it was proposed to use the double-bounded dichotomous choice (DBDC) method. This method requires respondents to accept or reject an initial offer, x, that they are presented with. If the offer is accepted, respondents are provided with a higher offer, $x + \alpha$, and similarly asked if they accept or reject the offer. If the initial offer is rejected, the respondent is presented with a lower offer, $x - \beta$, and asked if they would like to accept or reject it. This process is repeated and the WTP can be inferred from the highest offer accepted by the respondent.

The motivation behind choosing the DBDC question format is that it avoids multiple problems presented by the other question formats. The likelihood of receiving multiple 'zero' responses and clustered responses of open-ended questions is reduced. Presenting respondents with a range of values and asking them to identify the amount they are willing to pay may yield lower results depending on the upper limit of the range. Empirical studies have shown that increasing the maximum offer in a range from €100 to €1,000 results in WTPs that are 30% higher.[5] Previous studies have also indicated that the payment card method can create a 'range bias' where responses are bias towards the centre of the range.[6] This is the result of respondents being uncertain of an answer, therefore their responses are anchored to the centre of the scale. DBDC questions can be carefully designed to provide precise ranges of estimates of WTP.

The concerns regarding the DBDC approach were considered and being addressed during the planning of the survey. The DBDC method may involve a 'starting point bias' as responses were biased downwards (upwards) if the initial offer is at the lower (upper) end of the scale. For instance, if a respondent were presented an initial offer of €x, their WTP may be lower than if the first offer were €5x. The potential for a 'starting point bias' can be eliminated by randomly allocating respondents an initial offer from a distribution of WTP values. The responses will initially be biased for each of the groups, however by averaging out these responses across all the respondents in the sample, the final WTP will be unbiased. The requirement for a larger sample size for this method was met by reviewing response rates and using appropriate methods including repeat mailing and telephone surveys as deemed necessary.

3.1.2 Willingness to Pay (WTP) and Willingness to Accept (WTA)

Willingness to pay and willingness to accept are two related concepts which can be used to assess respondents' value of information. The payment question can either be phrased as the conventional 'What are you willing to pay (WTP) to receive data provided by the Aeolus satellites?', or in the less usual form, 'What are you willing to accept (WTA) in compensation for giving up use of your current service?' In theory, the results should be very close. However, when the two formats have been compared, WTA significantly exceeds WTP.[7] The difference can be explained by the behavioural bias known as the endowment effect, which is the result of reference dependence and loss aversion. Reference dependence refers to respondents requiring more in compensation for losing a good (WTA) than they would be willing to pay for it (WTP), since possession of the good becomes their reference point. Loss aversion means they need more compensation to accept losing it.

For the context of this study, WTP questions seemed more appropriate for several reasons. WTA measures of economic value for environmental related studies are seldom used. (Brown and

[5] Ternent, L., & Tsuchiya, A. (2011). A note on the expected biases in conventional iterative health state valuation protocols. *The University of Sheffield HEDS Discussion Paper*

[6] Henderson, J. E., & Dunn, M. A. (2007). Investigating the potential of fee-based recreation on private lands in the Lower Mississippi River Delta. *Southern Agricultural Economics Association Meetings*

Rowe, R.D.; Schulze, W.D. and Breffle, W.S. 1996, A Test for Payment Card Biases. Journal of Environmental Economics and Management, vol. 31: 178-185.

[7] Booz & Company. (2011). Cost-Benefit Analysis for GMES. European Commission: Directorate-General for Enterprise & Industry

The Economist. (2010). Carrots dressed as sticks. *The Economist* , p. 72.

Kahneman, D., Knetsch, J., & Thaler, R. (2009). Experntal Tests of the Endowment Effect and the Coase Theorem. In E. Khalil (Ed.), *The New Behavioral Economics. Volume 3. Tastes for Endowment, Identity and the Emotions. Elgar Reference Collection. International Library of Critical Writings in Economics, vol. 238.* (pp. 119-142). Cheltenham, U.K. and Northampton, Mass.

Gregory[8]) WTP questions are conceptually appropriate and commonly used to provide policy makers with information regarding the economic value of nonmarket environmental assets. WTP identifies a purchase price, relevant for valuing the proposed gain of a good, while WTA identifies a selling price, relevant for valuing a proposed relinquishment. This makes it more appropriate to use WTP when considering the objective of this study – assessing the benefit of data provided by the Aeolus satellite.

3.2 Scope of the Study

3.2.1 Sampling – Identification of relevant population

As outlined in the project proposal, a key component of Work Package 2 involved identifying priority sectors for the study. Given the ubiquity of weather data in decision-making amongst individuals, firms, and public institutions, sectors were prioritised in which the relative size of economic, environmental, and social impacts is likely to be the most significant. Prioritisation will aid in the identification of key decision makers that will constitute the sample of the analysis. As a result, the analysis is grounded in a more nuanced understanding of each sector's specific requirements in terms of meteorological information and data, and the potential variation in the value of information which may result.

3.2.2 Selection of the priority segments

The following recommendations are a product of accumulated firm experience at London Economics and desk-based research. In addition to the expertise of our Space Team, our Behavioural Economics Team has advised governments and European agencies for over 15 years and completed a multitude of VOI and WTP experiments. We have also established a strong position in weather related socio-economic studies. Prioritisation is largely based on relative size of economic, environmental, or social (i.e. number of people affected) impacts reported in previous studies, in ESA case studies, or in other preliminary research. The applications identified in the Red, Amber, and Green (RAG) assessment table, reflects the range found in other weather forecast-related CBAs.

Table 2 Priority market verticals

Weather and wind (forecast) dependent verticals	Priority (RAG rating)	High-level logic
Agriculture and Forestry	Yes	Crucial applications for farmers, with agricultural efficiency and outputs impacting all citizens. Additionally, forestry is particularly sensitive to changes in rainfall and droughts, which can lead to forest degradation, loss of soil fertility and forest fires, the use of weather services can empower operators to mitigate the risks associated with these effects and optimise operations.
Climate science and research	Yes	Large number of use cases in enabling people and businesses to adapt to atmospheric conditions. Critical to understand and predict climate events to prepare for disasters.
Construction	Yes	Estimated benefits from lives saved due to weather forecasts in UK construction industry alone total £34m p.a. in 2006. Significant benefit when applied across Europe, and hence a priority sector.

[8] Brown, C, B., & Gregory, R., (1998). Why imethe WTA-WTP disparity Matters, *Ecological Economics, vol. 28 (pg. 323-335)*

Weather and wind (forecast) dependent verticals	Priority (RAG rating)	High-level logic
Defence	No	Important but limited applications in Crisis Area modelling, bombing techniques, training exercise efficiency and other Defence-sector situations.
Disaster preparedness and response	Yes	An estimated damage of €6.5bn is inflicted per year in Europe due to extreme temperatures and flooding. Accurate and timely prediction enables improved mitigation and response, making this a priority application.
Energy and Water Supply	Yes	Gray (2015), identified Electricity, Gas, and Water Supply to be one of the top 4 most weather dependent sectors in the UK economy. In addition to the management of day-to-day operational activities and protection of infrastructure, weather forecasts may be critical to the efficient functioning of utilities markets. Wind farms in the North Sea will rely on accurate predictions for power generation and costs savings
Health	Yes	The use of weather services can help manage vector-borne diseases, pollutants, and allergies. Weather services can also provide information to for severe weather and reduce related casualties. Like other sectors, relevant to day-to-day operational activities, such as patient transport in health sector.
Manufacturing	No	Use in meeting weather-driven customer demand through stock planning, but generally understood to produce marginal financial efficiencies.
Mining and quarrying	Potential	The usage of weather predictions affects the sector by allowing operations to take place with lower health and safety risks, and a more efficient allocation of resources. Gray (2015), identified mining and quarrying to be one of the top 4 most weather dependent sectors in the UK economy.
Offshore oil & gas	Potential	Atmospheric dispersion models may be used in the event of large industrial incidents, and cost savings in helicopter operations, rig movements, and diver support vessel operations from improved meteorological data could be worth as much as £10m p.a in the UK. Further work to be done to determine accuracy of this figure and relevance of this amount versus other applications.
Transport and logistics	Yes	All modes of transport including maritime, road, aviation and rail are considered. Many lives are saved each year through improved diversions around storms. In the UK aviation sector for instance, financial savings from forecast-enabled more cost-efficient routes, reduced flight delays, and environmental benefits are worth hundreds of millions of euros and hundreds of thousands of tonnes of CO_2.
Tourism	Potential	Short-term forecasts are used extensively in the tourism sector by operators. For example, snow forecasts can determine the need for snow production systems in ski areas.
Volcanic ash monitoring	No	Volcanic ash, particularly from Icelandic volcanoes, has the potential to impact aviation and other sectors. There have been no major events since 2010, and hence due to limited frequency inclusion in this analysis isn't considered appropriate. (Included in disaster preparedness and response)

Note: Confirmation of priority, potential priority, and non-priority applications will be carried out with appropriate stakeholders in due course.

Source: London Economics analysis of the literature

Final Selection

Given the ubiquity of weather data in decision-making amongst public institutions, one key activity was to down select the primary market segments the present pilot study could cover. **Met offices** are central organisations to weather forecasts and information dissemination and prior beliefs indicate that there are most likely to engage with the study. The **climate** segment appears to be a key segment due to the current urgency and the need for global observing systems to derive robust models and tackle climate change. The **energy** sector is entangled to the climate crisis and will contribute to achieving the climate goals of the European Union. The causal relationship between weather variation and energy consumption (and therefore production) makes the segment very important to the analysis, in particular renewable energy production. Finally, the transport and logistics segment was initially considered to be a good candidate but proved too wide to include all modes of transport. The **aviation** sector was determined to be a compelling segment for inclusion due to its vulnerability to winds in different layers of the atmosphere and its contribution to carbon emissions.

3.3 Survey Design

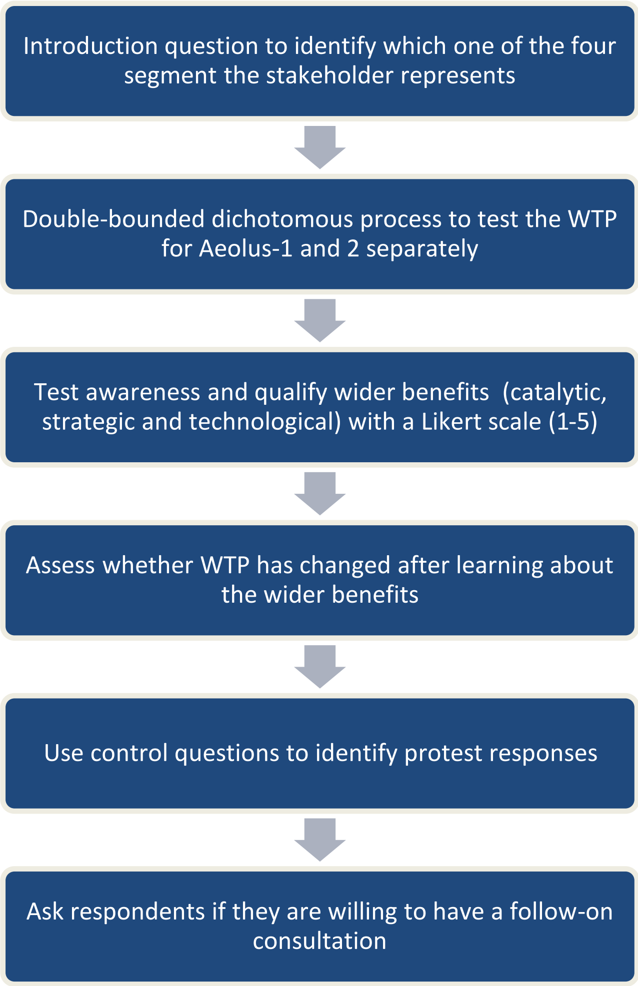
The survey began by asking respondents which segment their organisation represented. Based on their response, they were then presented with a tailored introduction which specified how Aeolus has improved accuracy of weather forecast predictions and how the data is useful within their segment. Following this information, respondents were asked how much their organisation would be willing to pay to access or continue accessing global Numerical Weather Prediction (NWP) and weather forecasting data at its current level of accuracy. The survey then provided some information on the Aeolus-2 satellite mission and asked stakeholders for their WTP for the continuation of Aeolus satellite missions to access data of greater accuracy. In the survey, respondents were asked about their knowledge of the wider benefits from Aeolus. Those benefits include:

- **Catalytic benefits** capture the value associated with wider benefits to third parties. The information generated from Aeolus data and NWP more broadly have an impact on the decision making of third-party organisations.
- **Technological benefits** are generated using a new technology in adjacent segments. For instance, ground-based lasers inspired from Aeolus technology are being developed to validate data captured by the satellite. In the future, this may support the collection of additional high-accuracy wind and atmospheric data at local scale.
- **Strategic benefits** refer to the benefits of having access to a unique set of data and information. This provides unique knowledge impacting strategic positioning and strengthening European space competitiveness.

To determine how they quantitatively value these wider benefits, respondents were asked to consider whether their organisation would be willing to pay more than their initial WTP. They were asked to provide intuition for their stated WTP values before being asked a few questions regarding their organisation. These questions allowed responses to be analysed based on organisation type, organisation size and how different uses for Aeolus data could potentially impact respondents' valuation of the data.

A copy of the full survey circulated to the stakeholders can be found in the Annex. A summary of the survey design is presented below in Figure 3:

Figure 3 Survey Design



3.3.1 Price Distribution

Illustration of WTP intervals

The double bounded dichotomous choice approach involved presenting respondents with an initial value and asking whether their organisation would be willing to pay this amount to access or continue accessing Aeolus data. These values were calibrated pre-launch and were decided following discussions with ESA, EUMETSAT and ECMWF.

Respondents were randomly allocated to groups P1, P2, or P3, and given two sets of 'Yes/No' choices. WTP is inferred from the highest offer accepted. Smart Survey, the platform used to implement the survey, enabled the randomisation of the initial value presented to the respondent. The following table illustrates the price distribution and offer intervals for a distribution with three combinations of initial offer, lower offer, and higher offer:

Table 3 Price distribution

Group	Initial offer (€)	Lower offer (€)	Higher offer (€)
G1	10,000	5,000	20,000
G2	20,000	10,000	30,000
G3	30,000	20,000	40,000

Respondents were given an initial offer:

- If they accepted, they were shown a higher offer and asked whether they accept or reject it.
  - If they then accepted the higher offer, WTP is inferred as lying in the interval between the higher offer and the highest market price.
  - If they rejected the higher offer, WTP is inferred to lie between the initial offer and the higher offer.
- If they rejected the initial offer, they were shown a lower offer and asked whether they wish to accept or reject it.
  - If they then accepted the lower offer, WTP is inferred to lie between the lower offer and the initial offer.
  - If they rejected the lower offer as well, WTP is inferred to lie between the lowest market price and the lower offer.

If respondents rejected both offers or if they accepted both offers, they were then asked an open question requesting them to state what they would be willing-to-pay. Further, respondents are asked why they were willing-to-pay the price they state, and, if they indicated a price of zero (or that they would not buy a guarantee) they were asked why they were not willing-to-pay to continue accessing these services. The motivation behind their response was important as this allowed protest responses to be highlighted, where respondents believed that access to the data should be free and therefore gave a valuation of 0.

3.4 Survey implementation

The survey was designed using Smart Survey and circulated with selected stakeholders online via email. For each priority sector, as many relevant organisations as possible were selected to maximise the number of responses.

A schedule with clear milestones was established to ensure a high response rate. The number of responses received at each milestone was monitored and a follow up email was sent to stakeholders who had not completed the survey by using repeat-mailing and reminder methods. One week after the second reminder, phone call interviews were to be carried out if response rates were **lower than 5%**. However, due to the high response rate, phone call interviews were not required. The survey milestone dates were agreed as below, with the survey being initially launched on the 01/12/2021:

Table 4 Survey schedule

Week	Date (approximate)	Step
Week 1	01/12/2021	Launch
Week 2	08/12/2021	
Week 3	15/12/2021	Reminder 1
Week 4	22/12/2021	Christmas break
Week 5	29/12/2021	Christmas break
Week 6	05/01/2022	Reminder 2
Week 7	12/01/2022	Contingency – Phone interviews
Week 8	19/01/2022	
Week 9	26/01/2022	Reminder 3 – Preliminary results
Week 10	02/02/2022	
Week 11	09/02/2022	
Week 12	16/02/2022	Reminder 4 - Last call
Week 13	23/02/2022	End

To **maximise the number of respondents**, the survey was designed to last no longer than **15 minutes**. The stakeholders contacted were likely to have many competing responsibilities, thus the survey was not a priority task for them to complete. In line with the previous statement, questions were designed to be **short and concise**. The wordings of questions were simple and labels self-explanatory to avoid respondent confusion, frustration, and drop out.

To support the uptake of the survey, a **letter of support** from the European Space Agency was also circulated to respondents when they were invited to fill out the survey. This provided credibility to the email campaign.

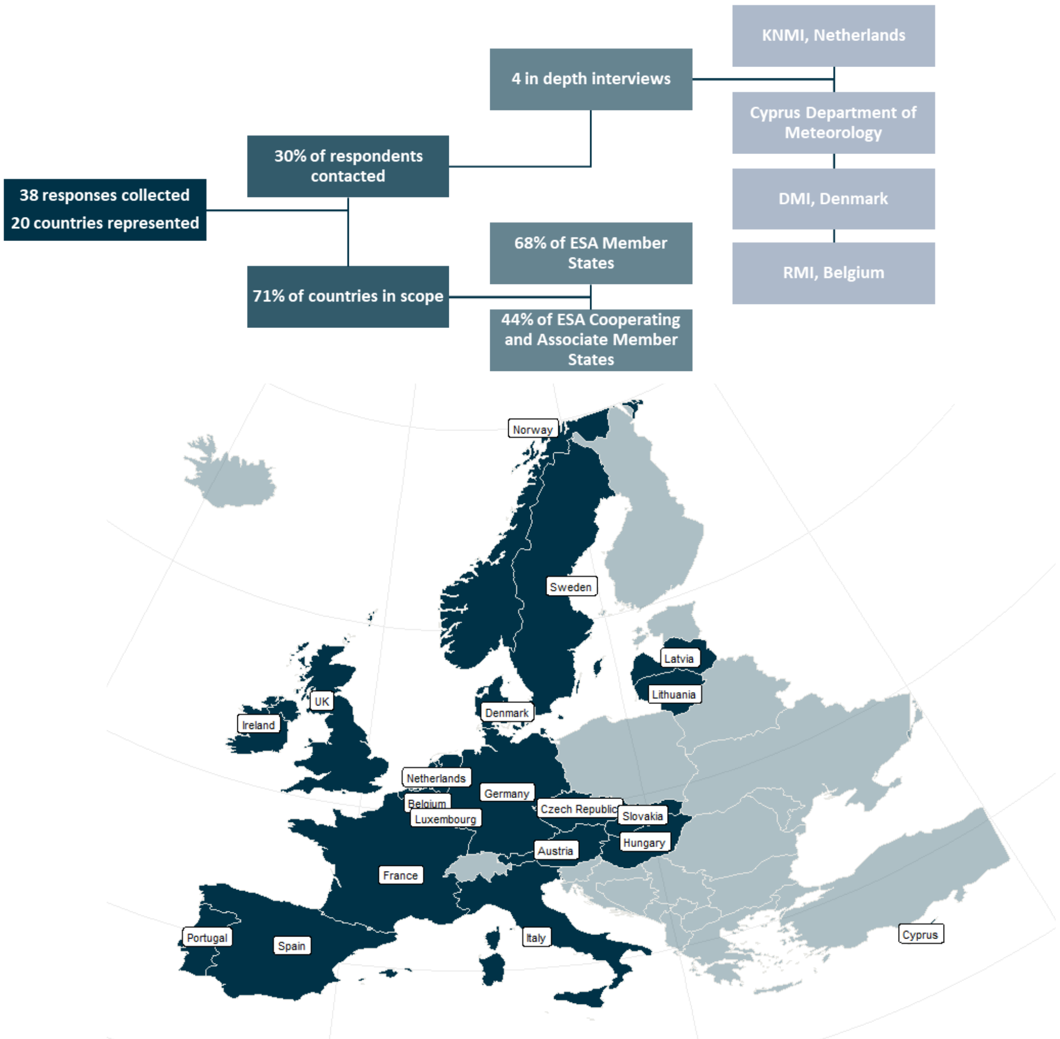
Finally, an option was provided to respondents to **share the survey** to colleagues and peers. This cascading method helped to improve the sample size, and therefore, the significance of results. It also allowed stakeholders to send the survey to members of their organisation who had more knowledge of Aeolus or a better understanding of the allocation of their organisation’s budget towards satellite missions ensuring results were more reliable.

4 Survey Engagement

The high level of engagement from European decision makers across organisations in the four priority segments validates the choice of the survey-based method and the engagement campaign. Over **70% of countries** in scope were represented in the survey results and results were received from 30% of the stakeholder list contacted. This high level of engagement provided insights from organisations of varying sizes and backgrounds. This has been an important consideration throughout the analysis.

Responses from **23 Met Offices** across Europe were collected, some of which were accustomed to using Aeolus data in their NWP models, providing useful quantitative and qualitative comments regarding the benefits of the satellite. **Four in-depth consultations** were conducted with organisations of different sizes and usage of Aeolus-1 data, highlighting a variety of benefits associated with those observations.

Figure 4 Survey Engagement and map of respondents

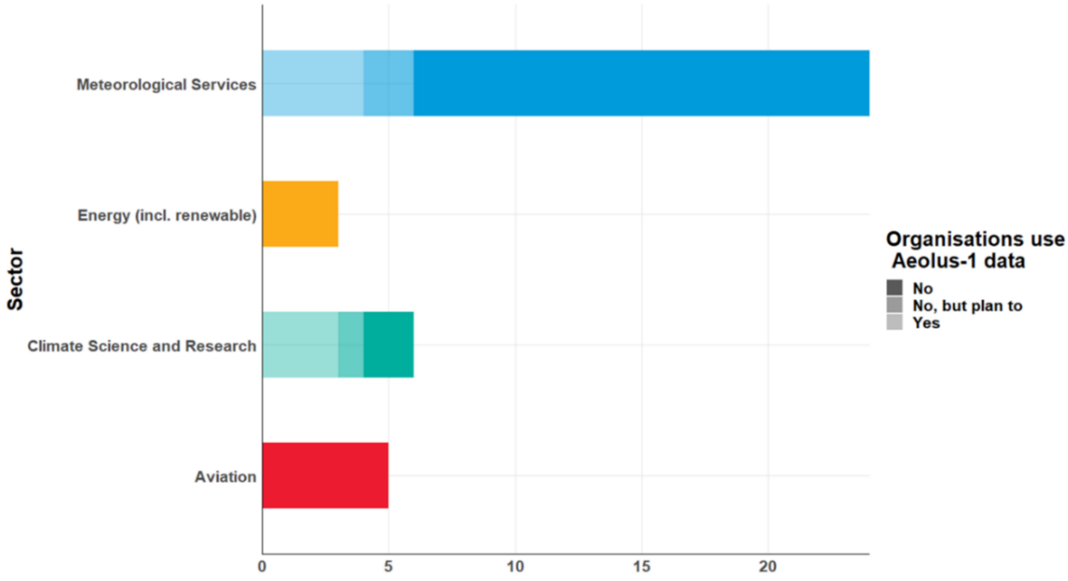


Source: London Economics analysis

Figure 5 shows that the meteorological services segment showed the highest level of engagement as they greatly contributed to the total number of responses received. With responses from 23 Met Offices across Europe, the following analysis of survey results considers valuations from offices of different sizes and with varying budgets. Responses from climate science and research centres were also well received as they were the segment which showed the second highest level of engagement. This level of engagement was expected as these two segments also expressed higher levels of experience with using the data currently in their numerical weather prediction (NWP) models. Some organisations responded stating that whilst they currently do not use the data in their models, their organisation had plans to assimilate the data in the future. The aviation and energy segments showed lower levels of engagement with the survey. This could possibly be explained by the fact that these organisations form part of the wider beneficiaries of the data so have less frequent or direct use of Aeolus satellite observations.

It is also important to note that some respondents may have been unaware that they rely on Aeolus data in their models, given that data inputs from organisations such as ECMWF is influenced and improved by Aeolus satellite observations.

Figure 5 Number of responses per segment



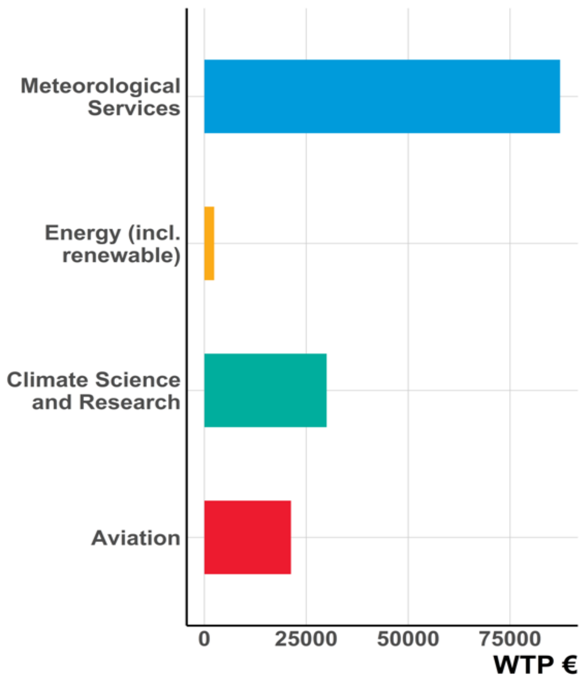
5 Aeolus-1 Satellite

This section provides an overview of the respondents' WTP to access or continue accessing Aeolus-1 data or the improved NWP models which rely on these data. An analysis of the qualitative findings is also presented with a detailed insight into the wider benefits of the satellite mission.

5.1 Willingness-to-Pay results

The average willingness to pay (WTP) among respondents is equal to **€60,000 per year**. Figure 6 presents the average WTP between segments. Results show there is substantial variance between segments. Respondents from national Met Offices have the highest average WTP averaging at **€87,300 per year.** Results also show this segment had the highest number of organisations with direct experience with using the data and that the average WTP of **organisations using the data is 5 times higher than those not using the data**. Climate science institutes showed the second highest average WTP of **€30,000 per year** with a few respondents already using Aeolus observations as part of their models.

Figure 6 WTP by sector



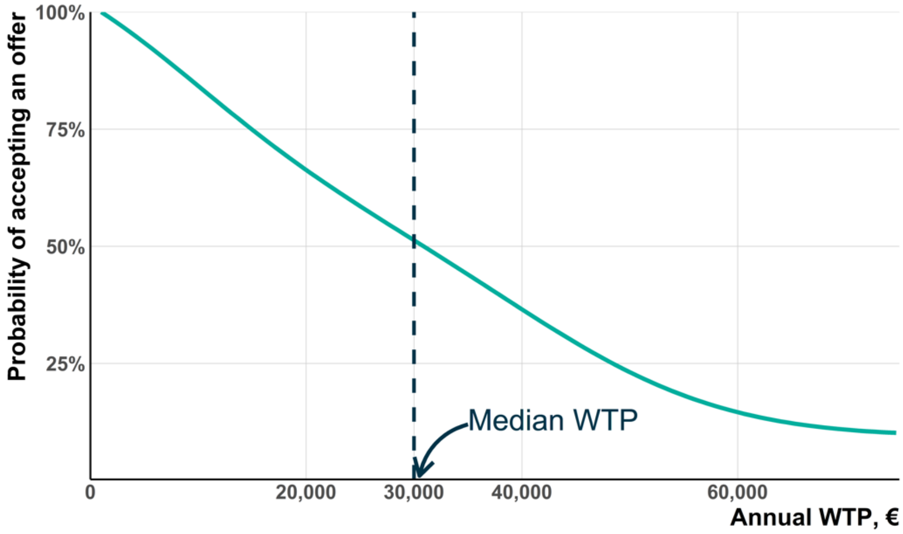
Source: London Economics analysis

Segments that are down the value chain exhibit a smaller WTP. Organisations in the aviation sector have an average WTP of **€21,200 per year.** The energy sector's WTP is **€2,400 per year** but this is not entirely representative of organisations WTP across the sector due to the small number of respondents.

Results show there is a difference in WTP values given by respondents based on the size of their organisations' budget. The survey shows that organisations with a budget below €5 million have a WTP of **€16,000** on average per year, while organisations with a budget above €5 million have a WTP over **5 times greater,** roughly equal to **€85,000 per year**.

This result is clearer when analysing in-depth results from the sample that can be used to derive a function showing how likely respondents are to be willing to pay for (or accept) an offer. Figure 7 shows that the probability of individuals being willing to pay for an offer decrease as the price of Aeolus-1 data increases. It highlights that when the price of the data increases over €30,000 per year, 50% of individuals are likely to reject the offer.

Figure 7 Aeolus-1 data demand as a function of the price



Source: London Economics

This key result shows that **free and open data policy reduces the barriers to adoption of data and therefore increases user uptake**. Without such policy, **budget constraints highly affect the WTP of individuals** and clearly shows that if the data was not provided under an open and free data access policy, many current users of Aeolus data and information would not have access, preventing the Value of Information to trickle down in the entire value chain of the European economy.

5.2 Analysis of the impact of wider benefits awareness on WTP

In the survey, respondents were asked about their knowledge of the wider benefits from Aeolus. Those benefits include:

- **Catalytic benefits** capture the value associated with wider benefits to third parties. The information generated from Aeolus data and NWP more broadly have an impact on the decision making of third-party organisations.
- **Technological benefits** are generated using a new technology in adjacent segments. For instance, ground-based lasers inspired from Aeolus technology are being developed to validate data captured by the satellite. In the future, this may support the collection of additional high-accuracy wind and atmospheric data at local scale.
- **Strategic benefits** refer to the benefits of having access to a unique set of data and information. This provides unique knowledge impacting strategic positioning and strengthening European space competitiveness.

To control for the difference in knowledge and awareness about the satellite's wider impacts, respondents were asked to state whether they were aware of the different wider benefits. Results were analysed based on 2 sub-groups of users: those with **complete awareness** of the wider benefits (having responded "Yes" to being aware of all 3 benefits streams), and those with **no or partial awareness** (having responded "No" to at least one of the benefits).

Results of the average WTP values based on respondents' knowledge suggest that those who have complete awareness of the satellite's benefits exhibit a WTP **44%** greater than others. While it remains challenging to isolate the value of each wider benefit, this result highlights that **better informed stakeholders value Aeolus data more than stakeholders with less information**.

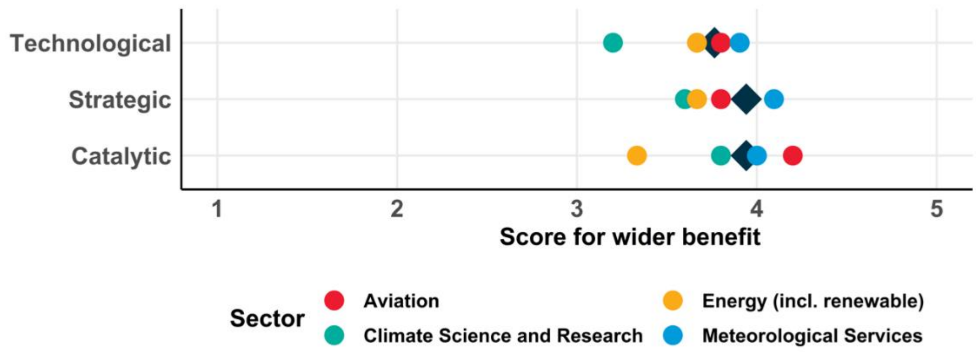
Table 5 Impact of awareness of wider benefits on WTP for Aeolus-1

Awareness of Wider Benefits	Average WTP for Aeolus-1
Complete Awareness	€73,300
Partial Awareness	€50,600

Source: London Economics analysis

In addition to awareness, the survey tested **how important the benefits are** to the respondents. Importance was assessed using a scale from 1 – "Not at all important" to 5 – "Extremely important" to gauge the wider benefits qualitatively. One immediate observation is that 98% of stakeholders ranked the benefits between 3 – "Somewhat important" and 5 – "Extremely important". The average scores by segment are illustrated in Figure 8 showing that overall, the strategic objective seems to be the most valuable to respondents followed by catalytic benefits and finally technological benefits.

Figure 8 Importance of Wider Benefits



Note: Diamonds represent the average score by benefits category

Source: London Economics analysis

The graph also highlights some heterogeneity between segments. The Aviation segment presents the highest value for the catalytic benefits. In the Energy segment, the strategic and technology benefits scored higher than the catalytic benefits.

Met Offices score strategic benefits the highest. This can be explained by their awareness of the importance of accessing this unique data and the criticality in the data sharing agreements between European partners.

In addition, respondents with a **complete awareness** (being aware of all the benefits) score these benefits on average higher than respondents with partial knowledge. This difference in average can be as high as **+0.6 points** for the technology benefits. This result confirms the importance of **communicating the different types of benefits** of such mission to the relevant stakeholders.

5.3 Assessment of the socio-economic benefits of Aeolus-1

This section details the computation of the primary and wider benefits of Aeolus-1. Based on WTP results across the 4 selected segments, the following section attempts to extrapolate the benefits of European decision makers across 1) primary data users, and 2) the wider ESA Member & Cooperating States' economies.

Primary Benefits of Aeolus-1 – Cost savings for data users

These primary benefits focus on the primary segment organisations and users which directly work with assimilating the observations into NWP models and relying on forecasting services for research and operations.

Table 6 below summarises the assumptions used to compute the benefits to Aeolus-1 data users.

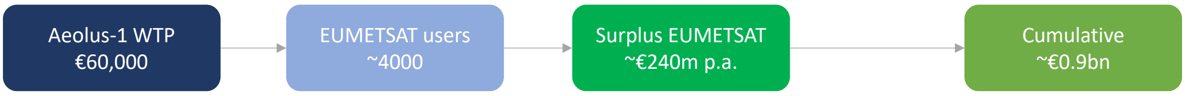
Table 6 Computation of Primary benefits of Aeolus-1

Assumption	Aeolus-1	Source
Average WTP	€60,000	WTP Analysis
Number of Users	Up to 4000	EUMETSAT registered users[9]
Discount Factor	4%	European Commission Guidelines[10]

Source: London Economics analysis

As presented in the section above, the primary benefits capture the surplus to organisations that benefit from the open data policy.

Figure 9 Calculating the Primary Benefits of Aeolus-1 over 3.5 years



Source: London Economics analysis

To calculate the primary benefits of Aeolus-1, the average WTP is taken from the results from this pilot study. To date, the exact number of users of Aeolus-1 data is difficult to estimate. The survey highlights that only a handful of organisations are direct users of the data. But some organisations might be utilising the information without being fully aware of it by using the information provided by NWP models (e.g. organisations receiving weather information from Met Offices integrating Aeolus data in their models).

To account for users of the data, it is assumed that the **4000 users** from EUMETSAT benefit from free access to this data. The survey questionnaire was directed to the individuals meaning the total value should be scaled at the user level.

The reported average WTP of those organisations amounts to **€60,000 per year**. The benefits of Aeolus-1 data could therefore amount up to **€240 million per annum**. Over the operational lifetime of the mission (3.5 years), these benefits accumulate to approximately **€900 million** for 4000 users, in real terms.

This result should be considered an **upper bound**. While it is assumed that the WTP is measured at the individual level, there is still some uncertainty about EUMETSAT users, notably in terms of which segment they belong too and how their position in the value chain potentially affects their WTP. Further analysis of the user base would enable the refinement of the results of this first pilot study.

[9] SciTechDaily. (2020). Aeolus Space Mission Goes Public – Already Hailed Success.
[10] EC. (2014). Guides to Cost-Benefit analysis of investment projects.

Wider benefits of Aeolus-1 – Contribution to European GDP

Table 7 below summarises the assumptions used to compute the benefits to ESA Member States.

Table 7 Computation of wider benefits of Aeolus-1

Assumption	Aeolus-1	Source
Operational Lifetime	3.5 years	ESA
Contribution to NWP (% error reduction)	4%	KNMI/ESA – measured average over Europe[11]
Weather Sensitive GDP (ESA Member States and Cooperating States)	€7.2 trillion (33% of GDP)	IMF 2020 (growth rate assuming 2% average growth p.a. over 10 years)[12]
Discount Factor	4%	European Commission Guidelines[13]

Source: London Economics analysis

The estimation of the wider benefits of Aeolus-1 has been outlined using a **conservative scenario** in which weather information increases weather-dependent GDP by **0.25%.** The analysis uses previous estimates from EUMETSAT study about the impact of NWP on GDP[14]. These wider benefits encapsulate the catalytic benefits to industry and society.

Weather information and accurate forecasting is vital across many sectors of the economy. It supports decision making to optimise activity, operate safely, and maximise productivity. In the Energy segment, the inability to store electricity at scale requires decision makers to have a consistent and reliable source for weather information to meet changing demand for electrical power. In 2020, wind accounted for 16% of the electricity consumed in EU27 and UK. Europe now has 220 GW of wind capacity.[15]

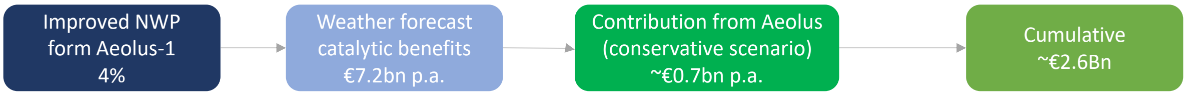
European Commission data shows that the production from renewable energy will grow substantially between now and 2050, taking an increasingly important share of the European energy mix. European Commission data shows that weather sensitive energy production means (solar, wind) will grow much faster than other sources and that offshore wind production is expected to grow over 15% per year, in the next decade[16].

With Aeolus-1 having a unique impact on global wind speed observations, the satellite would particularly benefit this rapidly growing wind energy sector in Europe and beyond, by improving decision making for identifying where wind turbines should be built. More accurate forecasts of wind speed leads to better execution of wind-power generation which could help balance the grid in a **more environmentally friendly** manner.

In the Aviation sector, reliable weather information is essential for predicting flight hazards such as turbulence or storms. Advanced warnings about weather conditions helps to minimise costly delays and supports human safety during flights.

[11] 3rd Aeolus NWP Impact and L2B product quality working meeting.
[12] International Monetary Fund – Data Portal
[13] EC. (2014). Guides to Cost-Benefit analysis of investment projects.
[14] EUMETSAT. (2014). The case for EPS/METOP second-generation: Cost-benefit analysis.
[15] Wind EUROPE. (2020). Wind energy in Europe.
[16]European Commission. (2020). EU reference scenario 2020.

Figure 10 Calculating the Wider Benefits of Aeolus-1



Source: London Economics analysis

While representing **less than 1% of data inputs**, Aeolus-1 **improves wind measurement and NWP forecasting accuracy by 4%**[17]. As highlighted in Table 6, weather sensitive GDP in ESA Member States and Cooperating States amounts to €7.2 trillion annually. Assuming weather forecasting information has an impact on GDP of 0.25%, the conservative scenario suggests that Aeolus-1 yields benefits of €0.7 billion per year. Over the 3.5 years operational lifetime, this amounts to **€2.6 billion** in real terms.

5.4 Current use and limitations of Aeolus Data

Results from this study highlight the disparity in usage of Aeolus data in European organisations across all four segments. Four national Met Offices and three Climate Research centres stated they currently use Aeolus data. None of the energy and aviation organisations had direct experience with using the data. However, it is important to note that these organisations may be unaware that they currently rely on the data through their use of ECMWF models. To mitigate this information gap, future studies could directly ask respondents how a degradation in NWP accuracy would impact their activities.

From the follow-on interviews conducted, it was clear that whilst some Met Offices, particularly smaller sized ones, acknowledged the value in the observations provided by Aeolus, they had no intention to assimilate the data from it in their current NWP models due to factors such as the lack of human capital available within the organisation, the complexity of data integration in NWP models or the limited computational power infrastructures.

5.5 Benefits of Open Data Policy

The result of this pilot study and the follow-on consultations conducted highlighted the **importance of an open data policy within Europe**. A substantial proportion of respondents highlighted that data from Aeolus should be provided for free. From follow-on consultations, it was evident that smaller organisations benefit greatly from being able to access the data for free due to their stricter budget constraints.

Some respondents flagged the importance of European data being freely accessible to academia and businesses. In some research centres, the integration of Aeolus data has revealed some issues in the models that were further corrected to deliver results even closer to reality.

Meanwhile, larger organisations highlighted the benefits of knowledge sharing where organisations freely share and exchange data from different satellites globally. This includes exchanging data from Aeolus with observations from Indian, Chinese and US satellites and was perceived as the "best commercial model possible".

[17] 3rd Aeolus NWP Impact and L2B product quality working meeting.

6 Aeolus-2 Satellite

This section provides an overview of the respondents' WTP to access Aeolus-2 data or the improved NWP models which will rely on these data. An analysis of the qualitative findings is also presented with a detailed insight into the wider benefits of the satellite mission. The case study also explores potential uses of Aeolus-2 data.

6.1 Willingness-to-Pay results

In the case of Aeolus-2, the average WTP among respondents is equal to **€62,000 per year**. Similar to the results for Aeolus-1, Met Offices exhibit the highest WTP value of **€86,200 per year**.

The study highlights the difference in average WTP values between larger and smaller organisations based on the budget for Aeolus-2. Results show that organisations with a larger budget of over €5 million had an average WTP **seven times greater** than organisations with a smaller budget. Compared to Aeolus-1, the average WTP for larger organisations is €6,000 higher and €3,000 lower for smaller organisations indicating the long term WTP is unlikely to change substantially within organisations.

6.2 Assessment of the socio-economic benefits of Aeolus-2

These primary benefits focus on the primary segment organisations which directly work with assimilating the observations into NWP models and relying on forecasting services for research (i.e. Met Offices and Climate researchers).

Table 8 below summarises the assumptions used to compute the expected benefits to Aeolus-2 data users.

Table 8 Computation of primary benefits of Aeolus-2

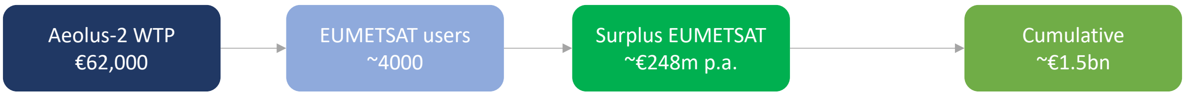
Assumption	Aeolus-2	Source
Average WTP	€62,000	WTP Analysis
Operational Lifetime	10 years	ESA mission design target
Number of Users	Up to 4000	EUMETSAT registered users[18]
Discount Factor	4%	European Commission Guidelines[19]

Source: London Economics analysis

The primary benefits capture the surplus to users and organisations benefitting from the open data policy.

Primary Benefits of Aeolus-2 – Cost savings for data users

Figure 11 Calculating the Primary Benefits of Aeolus-2



Source: London Economics analysis

[18] SciTechDaily. (2020). Aeolus Space Mission Goes Public – Already Hailed Success.
[19] EC. (2014). Guides to Cost-Benefit analysis of investment projects.

To calculate the primary benefits of Aeolus-2, the average WTP is taken from the results from this pilot study which elevates to €62,000 per year. To account for users of the data, the number of EUMETSAT users is taken. Benefits of Aeolus-2 data could therefore amount up to **€248 million per annum**. Over the targeted operational lifetime of the mission (10 years), these benefits accumulate to approximately **€1.5 billion** for 4000 users, in real terms.

In future studies, accounting for specificities of the users registered on the EUMETSAT platform would contribute to refining the results. Within group/segment in-depth analysis would **increase precision in the VOI** estimate and enable **refining questionnaires** and labelling. This would have immediate effect to **increase the number of responses** as respondents would feel closer to such studies, as Meteorological organisations are in the current case.

Moreover, the future uptake of users should be explored in a follow-on study. Consultations and open questions in the survey revealed that the uptake in the wind energy industry could rise substantially. Wind Europe[20] is the largest European wind energy association with over 490 members, including energy regulators, renewable energy plant planners, developers, and operators, as well as insurers, and more. Knowing that Aeolus data could contribute to energy forecasts, these 490 organisations represent a potential set of users for Aeolus-2.

The number of organisations in the wind energy industry is likely to grow over the next decade given Europe's ambitions to further develop on and offshore capacity. In addition, there is likely to be uptake in other segments as the benefits of wind data becomes more evident to certain industries (e.g., insurance, construction, maritime, etc.).

The analysis of the impact of awareness on the WTP shows that users with a complete awareness of the benefits of Aeolus have a WTP 44% higher than those with less information. This highlights the **importance of communicating with and educating** potential users about the applications of wind data from Aeolus. A greater engagement from potential users could boost the uptake of an operational mission.

Wider Benefits of Aeolus-2 – Contribution to European GDP

Table 9 below summarises the assumptions used to compute the benefits to ESA Member States.

Table 9 Computation of wider benefits of Aeolus-2

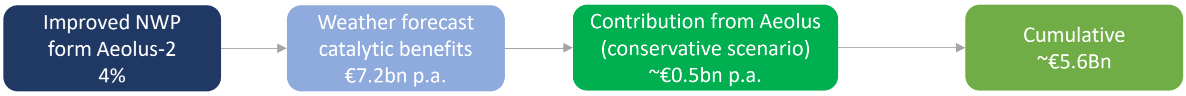
Assumption	Aeolus-2	Source
Operational Lifetime	10 years	ESA mission design target
Contribution to NWP (% error reduction)	4%	KNMI/ESA – assumed conservative average over Europe[21]
Weather Sensitive GDP (ESA Member States and Cooperating States)	€7.2 trillion (33% of GDP)	IMF 2020 (growth rate assuming 2% average growth p.a. over 10 years)[22]
Discount Factor	4%	European Commission Guidelines[23]

Source: London Economics analysis

[20] Wind Europe. https://windeurope.org/about-wind/.
[21] 3rd Aeolus NWP Impact and L2B product quality working meeting.
[22] International Monetary Fund – Data Portal
[23] EC. (2014). Guides to Cost-Benefit analysis of investment projects.

The estimation of the wider benefits of Aeolus-2 has been outlined using previous estimates from EUMETSAT study about the impact of NWP on GDP[24], following **a conservative scenario** in which weather information increases weather-dependent GDP by **0.25%.** Wider benefits encapsulate catalytic benefits resulting from better wind measurement and improved NWP to industry and society.

Figure 12 Calculating the Wider Benefits of Aeolus-2



Source: London Economics analysis

The prospective wider benefits of Aeolus-2 have also been calculated. It is estimated that like Aeolus-1, the follow-on mission will improve forecasting accuracy of NWP models by 4%. This is a conservative estimate and only reflect current observations from Aeolus-1 and some stakeholders mentioned that improvements to measurements (up to 8% improvements of NWP) could be envisaged for the operational mission.

As highlighted in Table 8, weather sensitive GDP in ESA Member States and Cooperating States amounts to €7.2 trillion annually. Assuming weather forecasting information has an impact on GDP of 0.25%, the **conservative scenario** suggests that Aeolus-2 yields wider benefits of **€0.6 billion** in 2030. Over the 10-year operational lifetime, this amounts to **€5.6 billion** (in real terms).

6.3 Benefits of operational mission and continuity of data provision

The data discontinuity between the two missions means global NWP centres will have under-utilised parts of systems developed to integrate Aeolus data during this period. This gap should be used by those organisations to develop and calibrate climate and NWP models based on the data from Aeolus-1. When Aeolus-2 becomes operational, with an extended lifetime of 10 years, the continuity of data provision over a longer time and the existence of robust models should yield more precise weather and wind information to European organisations.

In-depth consultations suggested that there is currently a gap in human capital to allow for highly technical tasks of assimilating data from Aeolus-1 in smaller Met Offices. Training schemes will be required to ensure that these skills are shared within Europe and generate **knowledge spill overs** between organisations. Sharing this intelligence could ease the assimilation tasks within smaller organisations, **incentivising them to a become involved to a greater degree in Aeolus or future Earth Explorers**.

6.4 Prospects for the wind energy sector

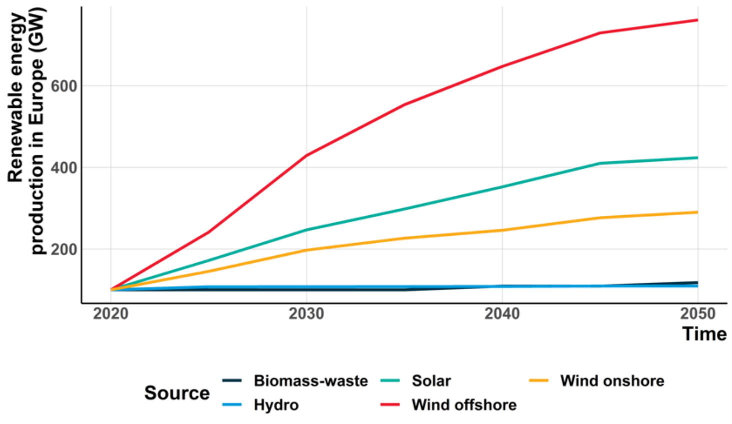
To meet climate mitigation targets, electrical power generation systems are required to change from relying on fossil fuels to renewables such as wind, solar, and hydropower. According to the European Wind Energy Association, 320 GW of wind energy capacity will be installed in the EU by 2030, 254 GW of onshore wind and 66 GW of offshore wind.[25] It has been estimated that with this capacity, wind energy would produce nearly 900 terawatt hours of electricity, equivalent to **30% of the EU's**

[24] EUMETSAT. (2014). The case for EPS/METOP second-generation: Cost-benefit analysis.
[25] Wind Europe. (2017). 'Wind Energy in Europe, Scenarios for 2030'. Available at: https://windeurope.org/about-wind/reports/wind-energy-in-europe-scenarios-for-2030/ [accessed 18 March 2022]

power demand. It is expected that by 2030 the wind energy industry would have investments in the EU amounting to €239 billion.

Data from the European Commission shows that the uptake of renewable energy production sources will be driven by wind, in particular offshore wind. In the next decade, the energy production from offshore farms will grow by 15% per year and will lead the energy transition in Europe as showed in the figure below.

Figure 13 European renewable energy production expectations between 2020 and 2050



***Source: London Economics analysis of EC data*[26]**

The rapid penetration of renewable energy sources into the European mix means that the energy grid is increasingly vulnerable to weather and climate variability. For example, a prolonged period of low wind speeds throughout summer and early autumn in 2021 heavily impacted the supply of wind energy. During this period, a UK-based power company SSE reported that its renewable assets produced 32% less power than forecasted.[27]

The latest IPCC report suggests that average wind speeds over Europe will reduce by 8%-10% as a consequence of climate change resulting in a reduction of wind energy potential by 8%-30% in southern Europe[28]. Understanding and monitoring those 'wind-droughts' is vital to ensure power systems can operate reliably.

With increasing demand for electrical power, it is essential that decision makers can plan how to **balance supply and demand** subject to accurate forecasting of production from wind farms. In addition, the increasing accuracy in NWP also makes it possible to create better forecasts of Europe's solar power output, which is another crucial and growing element in Europe's mix of renewable energy sources.

The Aeolus programme can improve the efficiency of European electricity production and contribute to future **European energy independence**.

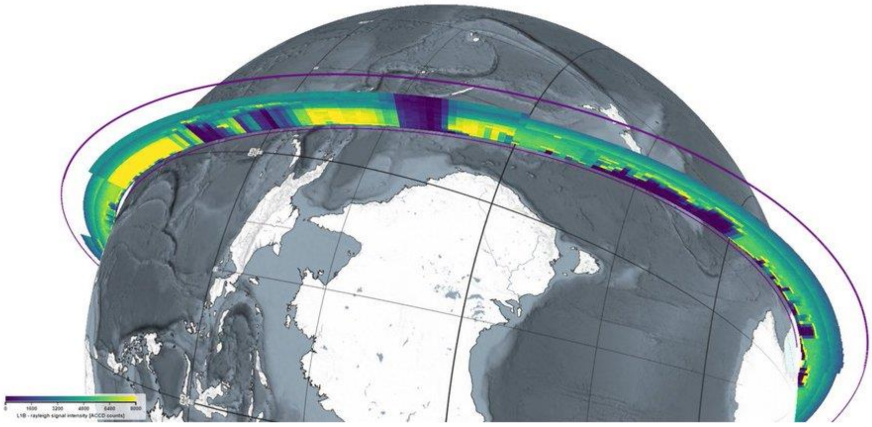
[26] European Commission. (2020). EU reference scenario 2020.
[27] Bloomfield, H., (2021). 'What Europe's exceptionally low winds mean for the future energy grid'. Available at: https://theconversation.com/what-europes-exceptionally-low-winds-mean-for-the-future-energy-grid-170135 [accessed 18 March 2022]
[28] IPCC. (2022). Climate Change 2022. Impact2, adaptation and vulnerabilities. (Page 2401, subject to edits from authors).

6.5 Prospects for climate science and disasters resilience

The benefits of Aeolus providing observations to help track changes in atmospheric dynamics were recently demonstrated in the Tonga volcanic eruption in the South Pacific, in January 2022. The laser light beam from the satellite was attenuated and blocked by an aerosol layer in the stratosphere, causing a dark blue area in the imagery as shown in Figure 14. The satellite provided a useful indication of the height of the ash cloud. The satellite also provided wind data for Hurricane Dorian in 2019 which was recorded as the most intense tropical cyclone on record to occur in the Bahamas.

These applications of Aeolus to extreme weather events provide an insight into the benefits the follow-on mission will also provide for weather forecasting and earth observation activities.

Figure 14 Satellite Imagery from the Tonga volcanic eruption in the South Pacific



Source: ***https://eox.at/2022/01/vires-for-aeolus-hunga-tonga-volcano/***

Aeolus-2 data will provide **European research centres with a competitive advantage to perfecting climate models** which will result in an **increase in research output** in Europe.

Moreover, Aeolus offers a resilient source of data when local observations are unavailable. The example of the COVID-19 pandemic has showed the importance of public satellite programmes such as Aeolus. While most aircraft which provide continuous and critical weather data were grounded, data from Aeolus-1 were used as an alternative input to NWP maintaining weather forecasts to a higher level than if the satellite was not available.[29]

6.6 Prospects for the insurance sector

The **insurance sector was perceived as one of the most interesting segments for Aeolus applications** by respondents. The risks associated with climate change are being increasingly explored by insurance and reinsurance companies. It is important for these companies to assess the potential physical risks of hazardous events such as storms and floods on individuals, businesses, communities, and countries. In 2019, a total of 409 natural disasters resulted in direct economic losses and damages of $232 billion worldwide.[30]

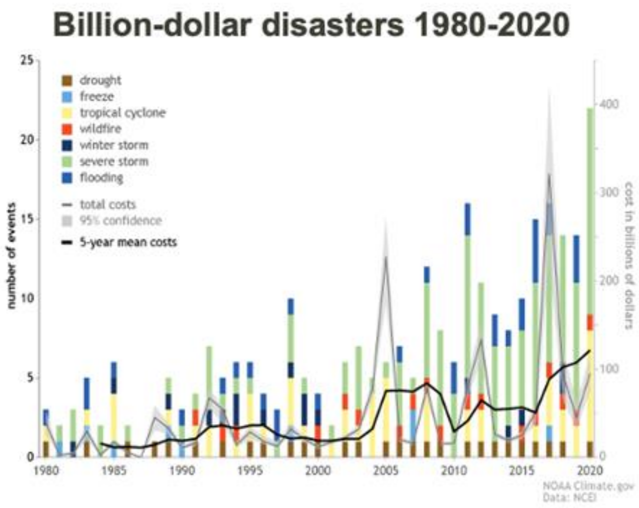
[29] ESA. (2020). COVID-19: Aeolus and weather forecasts

[30] Surminski, S., (2020). 'Climate Change and the Insurance Industry: Managing Risk in a Risky Time'. Available at: Climate Change and the Insurance Industry: Managing Risk in a Risky Time - Georgetown Journal of International Affairs [accessed 23 March 2022]

Understanding climate models and predicting weather events presents insurance companies with a business opportunity as there is currently a 'protection gap' with only a small proportion of these events being insured. Due to the high unpredictability and difficulty of forecasting disasters, insurance companies struggle to assess and quantify possible losses with sufficient accuracy.

This difficulty leads to a lack of insurance on disaster risks unless customers are charged very high premiums. With Aeolus observations improving accuracy in NWP models, insurance companies can benefit from greater precision when forecasting potential damage due to extreme weather events, particularly hurricanes and windstorms. This effect will play out even more strongly in the future, as the number of billion-dollar disasters is rapidly increasing due to the growing impacts of climate change and the overall economic growth worldwide.

Figure 15 Billion-dollar disasters 1980-2020



Source: NOAA

7 Conclusion

This study assesses the value and quantifies the current and prospective benefits generated by Aeolus-1 and 2 satellite missions. Using a value of information (VOI) framework, this investigation directly measures what decision makers are willing to pay to access data for enhanced decision making. The research also identifies barriers to adoption in the context of the mission, in particular the absence of **open data policy**.

Aeolus is a weather forecasting input and a **public good**, meaning it is **non-exclusive** and **non-rivalrous.** Agents who invest in weather forecasting cannot extract the full monetary value of the investment while direct users are public organisations that provide a service for society and do not charge prices equivalent to their costs. Therefore, the benefits of Aeolus predominantly **accrue to end-users**, who benefit from the improvements in numerical weather prediction accuracy without explicitly knowing that this is attributable to Aeolus. Reflecting the rationale behind a public good investment, these catalytic benefits are found in the results to outweigh direct benefits to users.

7.1 Key Valuations

This study finds that the total benefits of Aeolus-1 data and information to European stakeholders and society amounts to **€3.5Bn** while Aeolus-2 could generate **€7.1Bn** over the lifetime of the mission. In both cases, the benefits **vastly exceed** mission costs of **€480m and €1,105m** (incl. EUMETSAT Doppler Wind Lidar Programme) respectively. The investigation found that the average willingness to pay (WTP) for Aeolus data is **€60,000 per annum.**

An additional benefit of the Aeolus-1 satellite mission is the significant improvement it brings to **Numerical Weather Prediction** and the related benefits that this has for European Society. Aeolus-1 data represents **less than 1% of the data** in NWP models with investments in the Aeolus-1 programme improving **numerical weather predictions by 4%**. Consequently, Aeolus-1 is contributing an additional **€2.6Bn to Europe's GDP** throughout its mission lifetime. By continuing the operations of the demonstrator, Aeolus-2 has prospects and future scope for use across several sectors, namely: energy, climate disasters and resilience, and insurance. Under the assumptions outlined in Case Studies 1 and 2, Aeolus-2 has the potential to build on existing mission success and contribute up to **€5.6Bn** towards European GDP during its lifetime.

Crucial to the uptake of Aeolus data is the presence of an open data policy. Assuming the 4000 users from EUMETSAT benefit from free access to this data and using results from the WTP analysis, the study projects savings of up to **€240 million** per annum in direct benefits from accessing free data, representing a total value of **€0.9 billion in user cost savings** over the missions' lifetime. The WTP experiment suggests that that under a different policy, higher costs would to too expensive for smaller organisations and would have a negative impact on their demand for Aeolus data. Thus, it is found that any deviation from open data policy is a **barrier to adoption** in the context of the Aeolus missions.

7.2 Caveats and Limitations

Important to note are the various caveats and limitations that are associated with this study. As outlined in section 1.4, the current number of users for Aeolus-1 data is difficult to estimate and only a few organisations are direct users of the data. However, some organisations may be using Aeolus data through various NWP models without being aware of it. Accuracy of the present pilot studies could be improved through further investigation into the Aeolus user base.

There are also caveats to be considered in relation to the survey. Several responses stated that satellite data was not useful, but this could be attributable to a lack of knowledge rather than an accurate assessment. In some cases, respondents were aware of the functional value of wind data but were not able to put a monetary value on it, highlighting an issue with the respondent identification process. It is also important to consider the 12 protest responses which may have arisen from respondents interpreting the questions as a pricing exercise- an indication of the challenge in framing a WTP questionnaire. Improvements on these dimensions would yield benefits for future VOI studies.

7.3 Discussion and Recommendations

The Aeolus-1 and 2 missions have generated significant benefits for the European economy. Socio-economic benefits, cost-saving benefits and indicated future prospects in the case of both missions have been quantified. It is clear from the findings that Aeolus data is valued by many organisations across the Meteorology, Climate Science, Aviation, and Energy sectors and that often these organisations demonstrate robust WTP. However, an open data policy is critical to reap the wider benefits of Aeolus data, which would be forgone due to the budget constraints of many organisations. As the risks associated with climate change become more apparent, there will be an increased need to monitor climate conditions with higher accuracy, potentially expanding Aeolus' user base. In particular, this increase in data demand and uptake across energy, insurance and climate sectors is anticipated. Overall, Aeolus has the potential to deliver positive results for Europe in a return on investment that exceeds the mission costs.

Based on the preceding results, this study supports the investment case for Aeolus-1 and 2 satellite missions and offers the following recommendations:

- An education campaign on Aeolus and its capabilities should be undertaken in order to encourage smaller organisations to become involved to a greater degree in Aeolus or future Earth Explorers.
- **An open data policy** should be maintained, given the significant influence on uptake which drives the wider benefits generated by Aeolus. Any deviation from an open data policy is likely to decrease the size of the Aeolus user base and resulting benefits.

Index of Tables, Figures and Boxes

Tables

Figures

Boxes

ANNEXES

Annex 1 Survey Questions

1. Please select which the main economic sector your organisation covers? *

- ☐ Climate Science and Research
- ☐ Meteorological Services
- ☐ Aviation
- ☐ Energy (incl. renewable)

2. Do you or your organisation use Aeolus-1 data directly (e.g. in models, predictions, analysis, etc.)?

- ☐ Yes
- ☐ No
- ☐ No, but plan to

3. Do you or your organisation use Aeolus-1 data directly (e.g. in models, predictions, analysis, etc.)?

- ☐ Yes
- ☐ No

☐ No, but plan to

4. With the information provided and your knowledge of the contribution of Aeolus to weather forecasts, would you be willing to spend €10,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

5. With the information provided and your knowledge of the contribution of Aeolus to weather forecasts, would you be willing to spend €20,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

6. With the information provided and your knowledge of the contribution of Aeolus to weather forecasts, would you be willing to spend €30,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

7. Considering you are willing to spend €10,000, would you be willing to spend €20,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

8. Considering you are not willing to spend €10,000, would you be willing to spend €5,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

9. Considering you are willing to spend €20,000, would you be willing to spend €30,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

10. Considering you are not willing to spend €20,000, would you be willing to spend €10,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

11. Considering you are willing to spend €30,000, would you be willing to spend €40,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

12. Considering you are not willing to spend €30,000, would you be willing to spend €20,000 annually to maintain access to those forecasts?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

13. With the information provided and your knowledge of the contribution of Aeolus to wind measurements and forecasts, would you be willing to spend €10,000 annually to maintain access

to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

14. With the information provided and your knowledge of the contribution of Aeolus to wind measurements and forecasts, would you be willing to spend €20,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

15. With the information provided and your knowledge of the contribution of Aeolus to wind measurements and forecasts, would you be willing to spend €30,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

16. Considering you are willing to spend €10,000, would you be willing to spend €20,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

17. Considering you are not willing to spend €10,000, would you be willing to spend €5,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

18. Considering you are willing to spend €20,000, would you be willing to spend €30,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

19. Considering you are not willing to spend €20,000, would you be willing to spend €10,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

20. Considering you are willing to spend €30,000, would you be willing to spend €40,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

21. Considering you are not willing to spend €30,000, would you be willing to spend €20,000 annually to maintain access to this data?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

☐ Yes

☐ No

22. What is the maximum amount you are willing to spend annually to maintain access to those data and/or forecasts? (Please enter a number) *

23. You previously said you were not willing to spend money to access or continue accessing Aeolus data and/or weather information.

Please select the reason for this answer. *

- ☐ Aeolus-1 is not valuable to me
- ☐ My budget is unable to cover the costs
- ☐ I shouldn't have to pay to support the existence of high-quality weather forecasting
- ☐ I could not decide/did not understand the question
- ☐ Don't know/Prefer not to say
- ☐ Other (please specify):

24. This question seeks to establish any knowledge you might have had about the impacts of Aeolus prior to filling out this survey. Please indicate below if you were aware of the following wider impacts: *

	Yes	No
Aeolus data are distributed to users (data integrators such as Met Offices) within three hours of the measurements being made. This enables the dissemination of improved short range weather forecasts of wind speed, turbulence, and extreme events, in a timely manner and in locations where data were previously scarce (e.g. over oceans, southern hemisphere, poles). This process contributes to the reduction of costs to civil aviation due to incidents, delays, and cancellations. We refer to these benefits as Catalytic benefits.	☐	☐
Aeolus provides unique data impacting strategic positioning of users and strengthening competitiveness and independence of European aviation organisations. We refer to these benefits as Strategic benefits.	☐	☐
Ground based lasers based on Aeolus technology are being developed to validate data captured by Aeolus. In the future, this may support the collection additional high-accuracy wind and atmospheric data at local scale (around airports for instance). In addition, during the 2020 pandemic, Aeolus also filled the gaps left by other sensors (such as aviation based observations) and contributed to the maintenance of accurate weather forecasts. We refer to these benefits as Technology benefits.	☐	☐

25. This question seeks to establish any knowledge you might have had about the impacts of Aeolus prior to filling out this survey. Please indicate below if you were aware of the following wider impacts: *

	Yes	No
Aeolus data are distributed to users (data integrators such as climate research centres) within three hours of the measurements being made. In addition, Aeolus provides direct observations of winds, including in areas previously unobtainable (e.g. over oceans, and earth's poles). This enables climate observatories to provide improved forecasts to end users (e.g. health impacts of air pollution, dust particles, etc.). We refer to these benefits as Catalytic benefits.	☐	☐

	Yes	No
Aeolus provides unique data impacting strategic positioning and strengthening European competitiveness in climate research. In particular, this access to data and information enables European institutions to better understand climate change mechanisms and in turn, prepare improved policy responses and adaptation. This provides Europe with strong leadership in environmental policy making. We refer to these benefits as Strategic benefits.	☐	☐
Aeolus data provides the information needed by scientists to better understand the relationship between wind, pressure, temperature, and humidity – thus generating new knowledge about atmospheric dynamics and the climate. In addition, the revisit time and global coverage of Aeolus fills gaps from other sensors (such as aviation based observations) and contributes to building valuable time series data. We refer to these benefits as Technology benefits.	☐	☐

26. This question seeks to establish any knowledge you might have had about the impacts of Aeolus prior to filling out this survey. Please indicate below if you were aware of the following wider impacts: *

	Yes	No
Aeolus data are distributed to users (data integrators) within three hours of the measurements being made. This enables meteorological organisations to provide improved short range weather forecast (including extreme events) to their users, in a timely manner. We refer to these benefits as Catalytic benefits.	☐	☐
Aeolus provides unique data impacting strategic positioning of users and strengthening competitiveness of European meteorological organisations in weather data and applications. We refer to these benefits as Strategic benefits.	☐	☐
Ground based lasers based on Aeolus technology are being developed to validate data captured by Aeolus. In the future, this may support the collection additional high-accuracy wind and atmospheric data at local scale. In addition, Aeolus is filling the data gaps left by aviation by providing observations where aircraft fail to collect data (e.g., during the 2020 pandemic, or at higher altitudes), hence contributing to maintaining the completeness of time series datasets. We refer to these benefits as Technology benefits.	☐	☐

27. This question seeks to establish any knowledge you might have had about the impacts of Aeolus prior to filling out this survey. Please indicate below if you were aware of the following wider impacts: *

	Yes	No
Aeolus data are distributed to users (data integrators) in less than three hours of measurements being made. This enables improved short range forecast of vertical wind speed and extreme events, supporting demand and supply forecasts, in the energy sector. We refer to these benefits as Catalytic benefits.	☐	☐
Aeolus provides unique data impacting strategic positioning and strengthening European competitiveness and in the energy sector. Aeolus contributes to improved wind power forecasting and which may reduce the need for additional balancing energy (e.g., imports), increasing countries' energy security. We refer to these benefits as Strategic benefits.	☐	☐
Ground based lasers based on Aeolus technology are being developed to validate data captured by Aeolus. In the future, this may support the collection of additional high-accuracy wind and atmospheric data and predictions at a local scale, to support the energy production in some specific areas (e.g. offshore wind power). In addition, Aeolus is filling the data gaps left by aviation by providing observations where aircraft fail to collect data (e.g., during the 2020 pandemic, or at higher altitudes) hence contributing to maintaining the completeness of time series datasets. We refer to these benefits as Technology benefits.	☐	☐

28. How important do you think catalytic benefits associated with Aeolus are to your sector?

As a reminder, catalytic benefits describe the wider benefits to end-users (e.g. industry).

Extremely important	Very important	Somewhat important	Not so important	Not at all important
☐	☐	☐	☐	☐

29. How important do you think strategic benefits associated with the development of unique satellite instruments are to your sector?

As a reminder, strategic benefits describe the wider benefits to European institutions similar to yours (e.g. competitiveness, leadership, independence).

Extremely important	Very important	Somewhat important	Not so important	Not at all important
☐	☐	☐	☐	☐

30. How important do you think technological spill overs associated with the development of advanced satellite instruments are to your sector?

As a reminder, technology benefits describe the wider benefits from technology development (e.g. technology transfer, spin-outs, knowledge transfer, etc).

Extremely important	Very important	Somewhat important	Not so important	Not at all important
☐	☐	☐	☐	☐

31. What are the other benefits better weather forecasts provides (or may provide) to your organisation? Please indicate in the box below all the perceived/foreseen benefits.

32. Given the information about wider benefits and the value you previously stated you were willing to spend, would you be willing to spend an additional €10,000 annually to maintain access

to Aeolus data and/or weather information? Note that this amount is in addition to your initial statement. *

- [ ] Yes
- [ ] No

33. With the information provided and your knowledge of Aeolus-2, would you be willing to spend €10,000 to access to Aeolus-2 data and/or access improved weather forecasting services?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

- [ ] Yes
- [ ] No

34. With the information provided and your knowledge of Aeolus-2, would you be willing to spend €20,000 to access to Aeolus-2 data and/or access improved weather forecasting services?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

- [ ] Yes
- [ ] No

35. With the information provided and your knowledge of Aeolus-2, would you be willing to spend €30,000 to access to Aeolus-2 data and/or access improved weather forecasting services?

Please keep in mind that this exercise requires your honest valuation. This is NOT a pricing exercise. *

- [ ] Yes
- [ ] No

36. Considering you are willing to spend €10,000, would you be willing to spend €20,000 to access to Aeolus-2 data and/or access improved weather forecasting services? *

- [ ] Yes
- [ ] No

37. Considering you are not willing to spend €10,000, would you be willing to spend €5,000 to access to Aeolus-2 data and/or access improved weather forecasting services? *

- [ ] Yes
- [ ] No

38. Considering you are willing to spend €20,000, would you be willing to spend €30,000 to access to Aeolus-2 data and/or access improved weather forecasting services? *

- [ ] Yes
- [ ] No

39. Considering you are not willing to spend €20,000, would you be willing to spend €10,000 to access to Aeolus-2 data and/or access improved weather forecasting services? *

- [ ] Yes
- [ ] No

40. Considering you are willing to spend €30,000, would you be willing to spend €40,000 to access to Aeolus-2 data and/or access improved weather forecasting services? *

- [ ] Yes
- [ ] No

41. Considering you are not willing to spend €30,000, would you be willing to spend €20,000 to access to Aeolus-2 data and/or access improved weather forecasting services? *

- [ ] Yes
- [ ] No

42. What is the maximum amount you are willing to spend to access to Aeolus-2 data and/or access improved weather forecasting services? *

43. Did you feel you were able to make the choices in these exercises in a realistic way? *

- [ ] Yes
- [ ] No

44. Why did you feel you were unable to make these choices in a realistic way?

Please select all that apply: *

- [ ] I could not imagine the scenarios used in these choices
- [ ] I did not understand the role of Aeolus
- [ ] I did not understand the questions
- [ ] My organisation does not rely on accurate NWP or weather forecasting information
- [ ] Don’t know
- [ ] Other (please specify):

45. Did you feel the amounts of money presented in these questions were realistic? *

- [ ] Yes
- [ ] No

46. Why do you feel that the amounts of money were not realistic?

Please select all that apply: *

- [ ] The amounts were too high
- [ ] The amounts were too low
- [ ] Don’t know
- [ ] Other (please specify):

47. Please enter the name of your organisation below

48. Which of the following ranges capture the current budget for your organisation? *

- [ ] < €500,000
- [ ] €500,000 - €1,000,000
- [ ] €1,000,000 - €5,000,000
- [ ] > €5,000,000
- [ ] Prefer not to specify

49. Which of the following best describes your organisations' usage of the satellite data and/or weather information? *

- [ ] Observation and Monitoring (of specific geographical areas, coastlines, forests)
- [ ] Research and Development
- [ ] Management and Planning (improving accuracy of prediction over natural disasters/risk management)
- [ ] Support to industry
- [ ] Other (please specify):

50. Please add any additional comments you may have about the survey:

51. The study may require in-depth interviews with respondents. Would you like to be contacted via phone or email for follow on questions? (non-responses are considered as default "no")

- [ ] Yes
- [ ] No

52. If Yes - Please enter the email address you would like to be contacted on

LE
London Economics

Somerset House, New Wing, Strand,
London, WC2R 1LA, United Kingdom
info@londoneconomics.co.uk
londoneconomics.co.uk
@LondonEconomics
+44 (0)20 3701 7700