Summary

In recent decades, the space sector has undergone rapid and transformative development, driven by technological innovations, policy reforms, and an increasing number of participants in the field. The advent of the New Space Economy (NSE) era is a crucial milestone in this progression. It is characterised by private enterprise involvement, broader democratisation of access to space, and innovative business models that diverge significantly from traditional government-driven space initiatives. In this context, sustainability is essential not only for preserving orbital capacity and ensuring the long-term use of outer space but also for equitably distributing the benefits of space activities across society and for effectively addressing global challenges such as climate change mitigation and disaster resilience.

In this context, the present thesis adopts a multidisciplinary approach to provide a comprehensive overview of sustainability in the space sector. The thesis is organised around two complementary levels of analysis. At the macro level, it investigates the governance and developmental trajectories of space sustainability through a systematic review of 254 scientific articles, complemented by a Delphi study involving 63 international experts. The systematic literature review identifies key thematic clusters, ranging from policy, law, and regulation to debris management, life support systems, resource utilization, and remote sensing. It assesses their alignment with the three pillars of sustainability, environmental, economic, and social, and the United Nations Sustainable Development Goals. The findings highlight a growing yet uneven recognition of sustainability principles across the space sector, emphasizing areas of convergence, such as the imperative of debris mitigation, and divergence, such as the allocation of responsibilities between private and public actors. The Delphi study further refines these insights by incorporating forward-looking perspectives, elucidating the technologies and governance mechanisms most likely to influence sustainable development pathways by 2040. Additionally, this study highlights how geopolitical factors may potentially influence experts' views on the future of space sustainability.

At a micro level, this thesis explores the contribution of space-based technologies, particularly Earth Observation (EO), to aviation sustainability. Using the ESA Aeolus mission as a case study, the assessment evaluates how satellite-derived wind profiles can improve the monitoring of wind gusts. These rapid, disruptive events affect safety and efficiency. The research compares satellite data with airborne campaigns and turbulence models, demonstrating that, despite some temporal and spatial limitations, Aeolus data provide valuable insights into wind variability in both the vertical and horizontal dimensions. Notably, the study finds that EO can supplement traditional methods by detecting gust spatial patterns, analyzing seasonal and interannual changes, and enhancing turbulence models via spectral fitting techniques.

Furthermore, the use of EO data for terrestrial applications, as illustrated by the case study, generates benefits that extend beyond the atmosphere. It contributes not only to sustainability on Earth but also in space by promoting the commercialization of EO data for sustainable purposes, thereby strengthening the economic dimension of space sustainability. From an environmental perspective, integrating multiple EO missions with shared observation goals reduces the need for additional satellite launches, thereby minimizing orbital congestion and helping preserve the long-term health of the space environment.

By integrating governance-oriented inquiry with applied technological analysis, this thesis demonstrates that the sustainability of space requires a comprehensive approach that acknowledges the interdependence among regulatory foresight, economic strategies, and technological innovation. Furthermore, it illustrates how EO, when strategically employed, can support both the long-term resilience of the space environment and the immediate needs of critical terrestrial sectors, such as

aviation. The primary contribution of this study lies in its integration of theoretical frameworks with practical applications, thereby establishing a foundation for future research and policy development in the pursuit of a more sustainable New Space Economy.