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New Earth Observation Mission Ideas (NEOMI) Initiative: Night Watch Project

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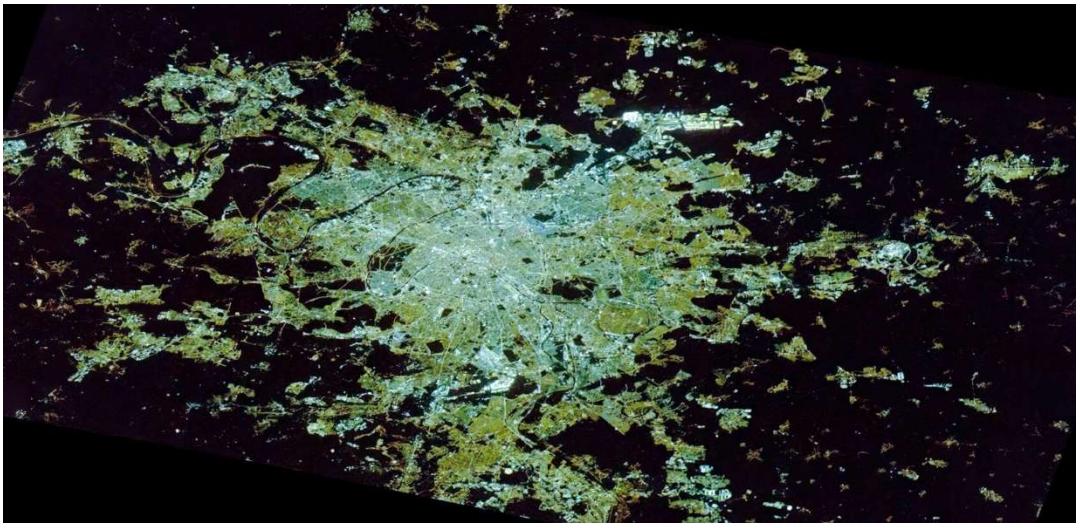
March 2025

There is growing demand for nighttime light data from space…

Images of the Earth's surface at night offer one of the most direct signatures of human activity visible from space, characterised by patchworks of glowing artificial light. These images can be used for diverse and far-reaching applications, including monitoring urbanisation, infrastructure development, energy use, population distribution, and the impacts of conflicts or disasters. Nighttime light data has even been used as a proxy measure for estimating economic development and population sizes, sometimes offering the best estimates in areas where other measures are difficult to obtain.[1]

Figure 1: Paris (France) at night as seen from the International Space Station



Source: NASA/ESA (2022)[2]

There are clear benefits associated with artificial light at night (ALAN) such as safety, security, and productivity. On the other hand, artificial light is also associated with negative impacts on human health. For instance, exposure to the blue light emitted by LEDs can disrupt human circadian rhythms, affecting sleep quality and potentially causing further health impacts.[3] As it is estimated that 80% of the world's population now lives in light polluted areas, this is a problem which is receiving increased attention in scientific literature, and there is rising demand for data at better levels of spatial and temporal resolution.[4]

[1] Addison, D., Stewart, B., 2015. Nighttime Lights Revisited: The Use of Nighttime Lights Data as a Proxy for Economic Variables. *World Bank Policy Research Working Paper*, 7496.
[2] NASA/ESA–S. Cristoforetti/A. Sánchez de Miguel, 2022. *Paris at night in 2022*. European Space Agency.
[3] Tähkämö, L., Partonen, T. and Pesonen, A.K., 2019. Systematic review of light exposure impact on human circadian rhythm. *Chronobiology international*, 36(2), pp.151-170.
[4] Levin, N., Kyba, C.C., Zhang, Q., de Miguel, A.S., Román, M.O., Li, X., Portnov, B.A., Molthan, A.L., Jechow, A., Miller, S.D. and Wang, Z., 2020. Remote sensing of night lights: A review and an outlook for the future. *Remote Sensing of Environment*, *237*, p.111443.

Artificial light pollution is also harmful to wildlife due to disruptive effects on biological processes that are linked to natural light cycles. For example, artificial light can alter the migratory patterns, feeding, growth, reproduction and survival of wild animals, and these impacts are exacerbated by the rise of LEDs and their increased emission of blue light.[5] Understanding the environmental costs and impacts of artificial light is essential in forming approaches to mitigate any negative or unintended consequences of ALAN.

While satellite imagery of ALAN underpins a broad spectrum of research, current sources of data are fragmented and limited in spectral range. Regular Earth observation (EO) satellites largely lack the calibration and sensitivity needed to effectively collect nighttime lights data. Dedicated ALAN satellites are designed to overcome these issues with higher sensitivity in low-light conditions. Europe has not yet established a dedicated mission or satellite specifically for studying ALAN, and current data comes from limited US and Chinese sources. One key source of ALAN data is the Visible Infrared Imaging Radiometer Suite DAY/Night Band (VIIRS), which is aboard NOAA's Joint Polar Satellite System. The broadband instrument returns one measurement across a wide spectral range, limiting the ability to differentiate materials and phenomena based on their unique spectral characteristics. Data that allows for such a differentiation is valuable, as it can provide important nuance for research, such as understanding how human health is impacted by different wavelengths of light. The SDGSAT-1 satellite, developed by the Chinese Academy of Sciences, is another existing source of ALAN data. However, accessibility to this data remains limited, with several stakeholders in the field of nighttime lights highlighting challenges and complexities involved in obtaining it, alongside a lack of clarity regarding the validity of the radiometric calibration. Other images, such as those taken on the ISS by astronauts, have also been used, although these are not taken systematically, and therefore have limited research applications.

… and this ESA project aims to support a first-of-a-kind European nighttime light satellite mission …

ESA's New Earth Observation Missions Ideas (NEOMI) call aims to support a new generation of actors working with ESA and leading future Earth Observation missions. Under this initiative, ESA allocated €250,000 to the Night Watch project to define requirements for a potential mission for gathering ALAN data and thus raise the project's scientific readiness level from 1 to 3. The team developed quantitative descriptions of these requirements,

[5] Gaston, K.J. and Sánchez de Miguel, A., 2022. Environmental impacts of artificial light at night. *Annual Review of Environment and Resources*, *47*(1), pp.373-398.

culminating in a Mission Description document[6] that can guide future ALAN-focused initiatives and support efforts towards Europe's first satellite dedicated to capturing this data.

The project was undertaken by an interdisciplinary consortium led by GFZ (Germany), the German Research Centre for Geosciences.[7] The rest of the consortium consisted of the Stars4all Foundation (multi-national), Leibniz Institute of Freshwater Ecology and Inland Fisheries (IGB, Germany), Faculty of Geo-Information Science and Earth Observation (ITC, Netherlands) at the University of Twente, and the Department of Physics at Cégep de Sherbrooke (Canada). External stakeholders from the US, Ireland and Spain also contributed to the project and mission description document.

This diverse international consortium brought together researchers from physics, development and human geography, and ecology, who investigated the requirements for realising the potential benefits of an enhanced ALAN data source. The project gave several individuals their first opportunity to work in the Earth observation domain, as well as with ESA for the first time, creating a clear route for user needs to be formed.

Figure 2: The Night Watch NEOMI consortium

The Night Watch project began in November 2022 and concluded in October 2023. The consortium investigated a large number of nighttime lights data uses before focusing on three areas in which research questions could be jointly addressed with one optical system: electricity access, migration barriers, and artificial light in the atmosphere.

The requirements derived from the project included the ideal number of geometric revisits, and a high spectral and spatial resolution. The sensitivity of optical systems was evaluated to a level that would allow the measurement of artificial light above the natural background radiance of moonlight, airglow and starlight. A large dynamic range to allow full imagery of large cities where light emissions are higher was also defined. These requirements provide a tool that can be leveraged for the system design of future missions, accelerating the potential developments of an enhanced ALAN mission.

[6] Kyba, C., Linares Arroyo, H., Degen, T., Abascal, A., Simoneau, A., Kuffer, M., Hölker, F., Aubé, M., Walczak, K., Espey, B. R., Sánchez de Miguel, A., Jechow, A. and Gyuk, G., 2024. Night Watch Mission Description Document (Scientific Technical Report STR ; 24/05), Potsdam : GFZ German Research Centre for Geosciences, https://doi.org/10.48440/GFZ.b103-24052.
[7] As of January 2025, known as GFZ Helmholtz Centre for Geosciences.

The team also evaluated existing technologies against these requirements and found current optical systems largely sufficient, with little need to raise the technological readiness level (TRL) of individual components. Instead, integrating these into satellite systems while maintaining sensitivity levels was identified as the next step towards an ALAN mission. The project therefore benchmarked requirements with regards to existing technologies to aid in the efficient allocation of resources for developments.

… which could revolutionise our understanding of disaster management, animal migration, and light pollution …

ALAN data can be leveraged in wide-ranging domains, notably in disaster management, health and well-being, and biodiversity conservation. For example, it can support electricity access and conservation in developing countries, through identifying economic activity and mapping the gaps in reliable access to electricity. Additionally, this data provides insights into energy usage, which can be leveraged for tailored policies to achieve more energy efficient cities and reduce light pollution. These improvements are crucial steps towards addressing global challenges, such as climate change and minimising the adverse effects of artificial light.

The issue of light pollution is growing globally, as the increasing transition to LED lighting alters the nighttime environment. For example, from 2014 to 2020 in Europe, emissions in the spectral bands associated with LED lighting showed an increase between 11% and 24%.[8] In particular, countries such as Italy and the United Kingdom have experienced notable increases in light pollution since the widespread adoption of LED lighting. Scientists note that this white and blue lighting is disrupting cycles and processes in both humans and animals.[9]

Improved ALAN data could aid in ecological research and therefore in the protection of wildlife. Several animal-related processes and activities are light-dependent and thus vulnerable to ALAN disruption, including migration pathways and circadian clocks.[10] This disruption can lead to imbalances in biodiversity and ecosystems through affecting food chains and the natural distribution of wildlife in a given area.

[8] Sánchez de Miguel, A., Bennie, J., Rosenfeld, E., Dzurjak, S. and Gaston, K., 2022. Environmental risks from artificial nighttime lighting widespread and increasing across Europe. *Science Advances*, 8(37), p.2.
[9] Sánchez de Miguel, A., Bennie, J., Rosenfeld, E., Dzurjak, S. and Gaston, K., 2022. Environmental risks from artificial nighttime lighting widespread and increasing across Europe. *Science Advances*, 8(37) and European Space Agency, 2022. *ESA astronauts help map Europe's light pollution from space*.
[10] Falcón, J., Torriglia, A., Attia, D., Viénot, F., Gronfier, C., Behar-Cohen, F., Martinsons, C. and Hicks, D., 2020. Exposure to Artificial Light at Night and the Consequences for Flora, Fauna, and Ecosystems. *Frontiers in Neuroscience, 14*, pp. 1-39.

… while delivering other valuable socio-economic benefits

While this project is an essential first step in realising future ALAN mission opportunities and the benefits this could bring to the downstream users of this data, ESA support has already led to tangible near-term benefits for the consortium. These benefits include the creation and strengthening of partnerships across research disciplines, positioning Europe as a leader in providing enhanced nighttime lights data to the international community.

Increasing scientific maturity and enhancing future mission specifications

ESA funding has helped mature the concept of a dedicated European nighttime light mission, advancing SRL from 1 to 3, defining requirements and a first-of-its-kind guidebook for future steps, alongside an innovative concept for improving sensing technology.

The Night Watch mission concept developed in the project has resulted in new quantitative information on the ALAN measurements required to fulfil scientific goals and user requirements. The study has therefore helped mature the concept of a dedicated nighttime light mission from scientific readiness level (SRL) 1 to 3.[11] These developments provide a first-of-its-kind guideline on the necessary sensitivity of systems which could be leveraged by ESA or national agencies looking to produce an ALAN-focused satellite. This could result in a new, enhanced nighttime lights satellite.

Beyond producing a new and unique tool in itself – a guidebook for future ALAN missions – this study has developed a mission concept with greatly improved sensing specifications compared to the current state-of-the-art technology. The modelling activities undertaken to determine Night Watch's sensitivity levels and orbit requirements have helped formulate a mission concept that could considerably improve on the current missions gathering ALAN data by way of heightened spatial resolution, spectral information, radiometric sensitivity and radiometric stability of systems. Importantly, the project team investigated both the improvements and compatibility of high sensitivities to create an enhanced, yet feasible, system concept for nighttime lights.

[11] ESA, 2023. *Scientific Readiness Levels (SRL) Handbook, Issue 2 Revision 0*, ESA-EOPSM-SRL-MA-4267, 10 February 2023, https://doi.org/10.5281/zenodo.14728217

Leveraging space to support multidisciplinary partnerships

The Night Watch project brought together an interdisciplinary project team, supporting cross-sector collaborations, both across the contracted organisations and with ESA.

The Night Watch project provided an opportunity for all individuals within the project team to work with ESA for the first time, offering a pathway for downstream users of ALAN data to interact more closely with the Agency. The involvement of these scientists provided a route to engage with the broader, cross-sectoral ALAN community, ensuring that their needs were integrated into the development of the ALAN mission requirements, and optimising the value they could derive from potential data returns.

ESA support for the Night Watch project also catalysed a new partnership and reinforced networks within an interdisciplinary and international consortium. The organisations involved (GFZ, Stars4all Foundation, IGB, ITC, and the Department of Physics at Cégep de Sherbrooke) span the fields of biology, astronomy and geoscience. A cross-sectoral collaboration between ITC and the Stars4all Foundation was catalysed for this project, while collaborations across the rest of the consortium were pre-existing but further strengthened through the study. These partnerships facilitate knowledge exchange across disciplines and strengthen avenues for future collaboration between the organisations.

Enhancing European competitiveness

ESA funding has supported the first steps towards establishing a new, enhanced ALAN satellite, which could position Europe as leaders in ALAN measurements for the international community.

While nighttime lights data has been applied to analyse trends across various sectors and disciplines, the project team emphasised that this remains an emerging field within the European space sector, supported by a relatively small research base compared to other areas of Earth Observation. Europe currently lacks a satellite dedicated to gathering ALAN data, which the team identified as a critical gap in its space capabilities. Such a satellite would not only unlock reliable access to ALAN data but also position Europe as leaders of providing enhanced ALAN data to the international community, supporting a wide range of applications and addressing existing and future societal needs.

The Night Watch project represents a crucial step toward closing this capability gap by laying the groundwork for a future mission. These developments could enhance Europe's non-dependence in this field, reducing reliance on data from countries like China and the

US, which currently dominate ALAN data collection. This would help strengthen Europe's resilience, mitigate challenges associated with accessing foreign datasets, and secure cost-effective and strategically reliable sources of nighttime lights data. Furthermore, the Night Watch mission could provide a step-change to the existing global capabilities, offering enhanced dynamic range and spectral coverage, while ensuring data integrity and continuity.

Preparing for missions and future development activities

ESA's support enabled the project team to leverage expertise gained from Night Watch for future proposals, continuing progress towards a nighttime light mission and supporting space sector growth.

The Night Watch project marked the team's first collaboration with ESA, offering valuable insights into the operations of a major space agency. Stakeholders highlighted that working with ESA enhanced their understanding of its decision-making processes and the precision required to define mission requirements, particularly during the preparation of the mission description document. This collaboration deepened the team's knowledge of ESA's operational standards and helped them adapt to the stringent demands of space technologies. These experiences position the project team to competitively pursue new opportunities within the space sector, leveraging their enhanced expertise. Furthermore, the team's experience with ESA processes equips them to engage effectively with similar clients in the future, including space agencies and other large institutional organisations.

By advancing the Night Watch concept, ESA funding has enhanced both the project team's capabilities and the concept's competitiveness for follow-on mission opportunities. Leveraging their experience, the team has submitted proposals for future missions, including the proposed EULE project for ESA's Earth Explorer 12 call and a DLR mission. These efforts, grounded in the expertise developed through the NEOMI project, demonstrate the team's commitment to advocating for the Night Watch concept. It also showcases ESA funding as crucial in driving the momentum towards a European nighttime lights mission, which could increase non-dependence and enable reliable access to enhanced ALAN data. In turn, this data could help address global challenges and advance Sustainable Development Goals, including research to develop sustainable cities and protect life on land.

Upskilling of project team members

This ESA project has upskilled scientists and researchers in the field of nighttime lights, contributing to at least 2 promotions, and enhancing the European ALAN remote sensing research base.

The ESA-supported Night Watch project played a key role in fostering the professional development of project team members. Stakeholders noted challenges in advocating for a dedicated nighttime lights satellite, predominantly due to it being an emerging field with limited heritage in previous relevant space projects, as well as where the experts are young and in relatively unstable career positions.

Through the project, understanding of both space missions and space agency operations were developed by stakeholders. They notably reported improving skills in strategic planning and defining mission requirements to the desired level of precision. At least two team members have since advanced to senior academic positions. One received a ~€650,000 Heisenberg fellowship, a prestigious award from the German Research Foundation which will support the creation of a position to enable further research and teaching on the development of night lights capabilities. Another became a postdoctoral researcher. This highlights that ESA funding helped support the professional development of early career professionals and strengthen the reputation and knowledge base of the project team's respective organisations. These advancements also enhance the team's capacity to further the mission concept and advocate for the importance of remote sensing of ALAN data. In the long term, this progress could strengthen the European research community, which currently lacks dedicated academic programmes in the domain.

Beyond new and enhanced technical skills, the activity helped develop project management capabilities. For example, one project team member noted that they were involved in coordinating meetings and documentation between the consortium and ESA. This allowed them to develop international and multidisciplinary coordination skills. People management was a crucial element of this, given the need to align different objectives to help reach a consensus. This further exemplifies that ESA funding supported upskilling through this activity, which can contribute to making future international and cross-sectoral projects involving these contractors and team members more efficient.

Supporting the publication of academic research

Expertise from the project has been leveraged for over 20 academic articles, which have already accumulated a total of 230 citations (as of February 2025). They have also already been referenced in 490 online news articles, including in high profile outlets such as the National Geographic.

The consortium has disseminated the findings of their ESA project by publishing research articles and mission description documents, which have been successful in reaching a wide audience within academia and beyond. For instance, a key impact of ESA funding was the project team's *Nature Earth and Environment* article, which was published in May 2024.[12] This publication has been downloaded over 2,000 times already, and has been referenced in a National Geographic article, as well as other news sources. This visibility helps enhance the project team's reputation within the scientific community.

The knowledge gained from the Night Watch project has been leveraged in publications which either study the direct impacts of ALAN, or leverage ALAN data to map global and regional trends. While the publication of articles was not the intended objective of the activity, the knowledge acquired has indirectly contributed to the publication of over 20 articles relevant to ALAN since the Night Watch project began in 2022, which have already accumulated a total of 230 citations across them (as of February 2025). These publications include research into mapping urban inequality from space, ALAN's impacts on bird migration patterns, and some complementary studies of light pollution using citizen science data. They have also had wider reach beyond the academic community, being referenced in a total of 490 online news articles, demonstrating a rising interest in space nighttime light data and its applications. This positions consortium members as experts within this emerging domain, increasing their reputation and potentially attracting future opportunities and collaborations in the field of nighttime lights.

Enhancing visibility through varied outreach strategies

The project team has undertaken various outreach activities intended for a diverse range of audiences, including at least 8 conferences during the project, as well as 6 BBC news articles.

Beyond publications, the consortium has also promoted the study and its scientific use cases through a range of outreach activities. During the project, the team attended at least 8 conferences and events. This helps raise the profile of the Night Watch project and the

[12] Linares Arroyo, H., Abascal, A., Degen, T., Aubé, M., Espey, B.R., Gyuk, G., Hölker, F., Jechow, A., Kuffer, M., Sánchez de Miguel, A. and Simoneau, A., 2024. Monitoring, trends and impacts of light pollution. *Nature Reviews Earth & Environment*, pp.1-14.

consortium organisations within the subsector, while also building momentum around potential future opportunities. Conferences include the biggest nighttime light conferences, such as the LPTMM conference in Austria, and the ALAN conference series (various locations). The project team are also planning to attend larger conferences beyond the ALAN research community, such as the ESA Living Planet Symposium in Vienna, which will be held in June 2025.

Alongside this, the project team have been in discussions with various national and regional agencies (e.g. councils, environmental agencies, and space agencies) to assess the demand for nighttime light data, and to build partnerships that could support future mission development. They have also been reaching out to companies to develop a consortium for a future ESA Scout mission proposal, although these discussions are at a relatively early stage.

Beyond conferences and meetings, one member of the project team – Dr Christopher Kyba – has also appeared in six BBC news articles, discussing the wider implications of ALAN to society, of which three have followed the Night Watch project. These articles are also pitched at different audiences, including 'science and environmental' articles and the 'sky at night' magazine, which are short summaries intended for the engaged public, as well as simple summary versions intended for children. Moreover, Dr Kyba's nighttime lights pictures were used by BBC News' Instagram page, receiving over 250,000 likes, further raising the profile of ALAN research in the public domain.

Would these benefits have been realised without ESA?

Stakeholders stressed that the abovementioned impacts are highly attributable to ESA support. For instance, several project team members stated that they were unlikely to have continued working in this area, or even remained in roles at research institutions at all, had it not been for this ESA project. Therefore, while the scientific publications highlighted earlier may be indirectly linked to the project outputs (e.g. focusing on different ALAN data use cases), they are still linked strongly to this ESA-funded activity, as they would have been unlikely to have materialised otherwise.

"This project was a big turning point in my career, and it has helped me get to the point where I have multiple other projects and opportunities" – Project team member from Stars4All Foundation

Moreover, some of the key upskilling impacts of the project have come from project team members working alongside ESA for the first time, and adapting to the requirements of the Agency, which would not have happened without the project.

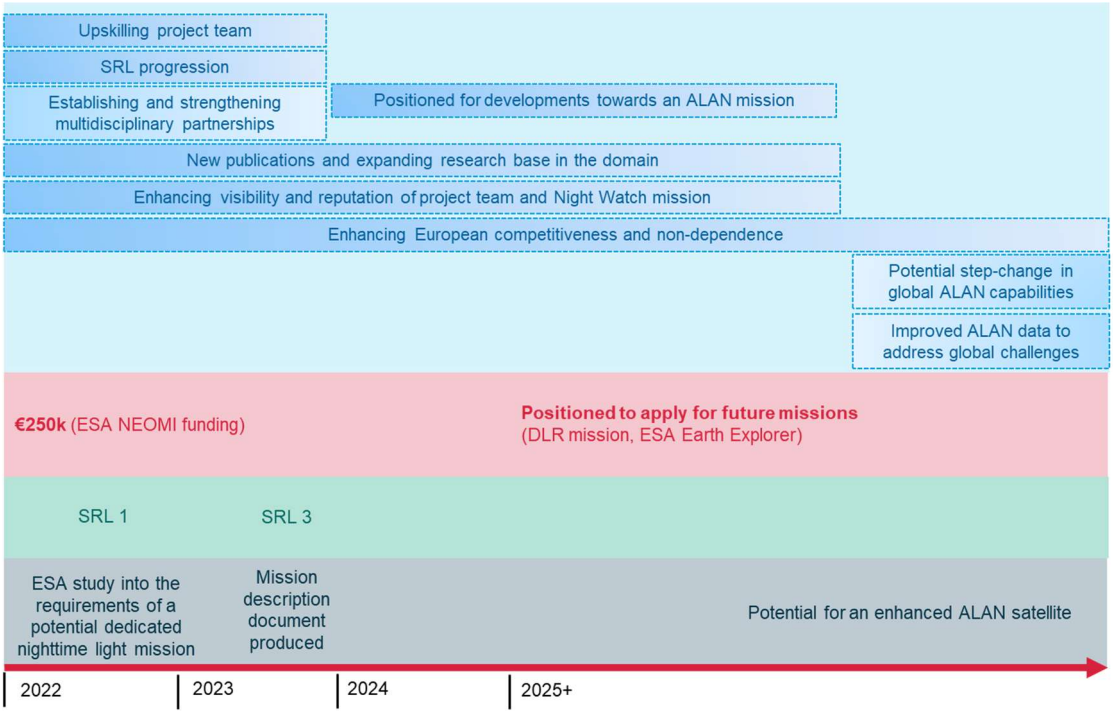
Next steps: Further development, further benefits

While a future mission is the ultimate aim of the Night Watch project, further scientific and technological maturation is required beforehand. The consortium will continue to discuss potential options with industry actors, and are likely to apply for another ESA Earth Explorer mission or other ESA Earth Observation missions calls in the future to drive the concept towards flight readiness.

This future mission would provide the global ALAN remote sensing community and downstream researchers with better data. This data could have improved spatial resolution, spectral information, and radiometric stability, providing researchers with better tools to understand the effects of ALAN on populations, ecology, and the environment. In turn, this information could enable better informed policies and mitigation measures, contributing to the development of smarter cities and infrastructure with optimised lighting systems, which successfully balance safety, energy conservation, health, and ecological and environmental factors. Alongside this, it brings the opportunity for the data to be commercially leveraged by actors such as energy providers to improve production efficiency internationally.

Below is a preliminary timeline outlining materialised and potential future benefits associated with the Night Watch activity.

Figure 3: Overview of the timeline of the Night Watch project and the potential associated benefits



Source: know.space based on data from ESA and the Night Watch consortium

Key priority indicators

Programme	FutureEO
Country	Germany, Canada, Spain, Netherlands
Activity cost	€250,000
Duration	12 months
Lead contractor	GFZ Potsdam (DE)
Sub-contractors	Cégep de Sherbooke (CA), IGB (DE), Stars4all (ES), University of Twente (NL)
SRL progression	1 to 3
Spin-in into the space sector	-
Jobs supported	5 individuals
New collaboration with ESA	5 (all organisations)
Partnerships created	ITC with Stars4all Foundation
Follow-on funding applied/secured	Applied for ESA Earth Explorer mission call (EULE project) and a DLR mission. Team is continuing to seek other funding opportunities.

Annex A: Publications and conferences

Publications

This list is only representative of the publications that the project team produced together under the Night Watch project and does not include an exhaustive list of the publications that have leverage knowledge from the project.

- C. Kyba, et al. (2024). Night Watch Mission Description Document. Available at: DOI:10.48440/GFZ.b103-24052
- H. Linares Arroyo, et al. (2024). Author Correction: Monitoring, trends and impacts of light pollution. Nature Reviews Earth & Environment. Available at: DOI:10.1038/s43017-024-00577-3

Conferences

- Paper presentation at the ESA Living Planet Symposium 2022 – Global Environmental Effects of Artificial Nighttime Lighting. Available at: https://www.researchgate.net/publication/365447002_N8_-_Global_Environmental_Effects_of_Artificial_Nighttime_Lighting
- Paper presentation at the 41st EARSeL Symposium 2022 – Mapping Access to Electricity and Urban Night Lights: Leveraging the Massive Repository of Astronaut Photography of the Earth. Available at: https://www.researchgate.net/publication/365447221_Mapping_Access_to_Electricity_and_Urban_Night_Lights_Leveraging_the_Massive_Repository_of_Astronaut_Photography_of_the_Earth
- Paper presentation at the Joint Urban Remote Sensing Event 2023 – Mapping the Invisibles: Global Urban Inequalities through Night Lights. Available at: DOI:10.1109/JURSE57346.2023.10144207
- Paper presentation at the 8th international conference on artificial light at night 2023 – Night Watch, a New Earth Observation Mission Idea Theme: Technology and Design. Available at: https://hal.science/hal-04224820