POLICY BRIEF PRESENTED TO SLIGO COUNTY COUNCIL JUNE 2023 - Building Climate Resilience in Sligo County through Ecosystem-based Adaptation, Smart Technologies, and Coastal City Living Lab

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101003534

EXECUTIVE SUMMARY

The EU SCORE project has been conducting research on building coastal resilience in the face of coastal hazards, sea-level rise and coastal erosion in Sligo County, through the Coastal City Living Lab (CCLL), Ecosystem-based Adaptation (EBA), Citizen Science and Smart Technologies like Low-Cost Sensors and Digital Twin (DT). The research findings could be key to informing local climate adaptation policy. This involves results about climate vulnerability and ecosystem-based adaptation based on surveys and participatory workshops with stakeholders; results from climate modelling and digital twin; results from improved monitoring such as through low-cost sensors, satellite data and storm surge modelling; as well as results from stakeholder engagement through the living lab model. This document presents a policy brief for Sligo County Council decision makers from the lessons learned so far from the SCORE results.

RATIONALE FOR ACTION ON THE PROBLEM

Sligo County, along with the rest of Ireland, could be exposed to 1 metre of sea-level rise and 1.9 degrees Celsius warmer temperatures in the Irish Sea, by 2100. Current adaptation plans and climate action strategies do not incorporate plans for long-term climate planning and adaptation. Sligo County has also been increasingly facing more frequent and intense climate hazards, such as windstorms, riverine and coastal flood events, heatwaves and droughts, coastal erosion, and snowfall events as well as changes in temperature (up to 1.6 degrees warmer by 2050 and 0.7 degrees warmer in 1981-2010 compared to 1961-1990) and precipitation patterns (up to 17% reduction in precipitation in summer and 19% increase in precipitation in winter). Ireland has also experienced extreme droughts in 1803–1806, 1854–1859, 1933–1935, 1944–1945, 1953–1954, and 1975–1977 (O'Connor et al., 2022). These have impact on local infrastructure, for example:

(i) River and pluvial flooding led in 2020 and 2021 led to damage to residential properties, closure of businesses (Mowlam Nursing Home) and transport networks, and disruption of public services. Projected increases in storms will expose Sligo to more riverine and pluvial flooding events.

(ii) Sea-level rise of up to 3mm since 1990 as well as coastal flooding and erosion pose a significant risk to Sligo, in terms of disruption of coastal habitats, infrastructure, and transport networks. This will increase with increasing projected sea-level rise.

(iii) Severe windstorms already affect energy supply and transportation networks in Sligo. These are projected to increase in frequency and intensity. Assets in Sligo are under major threat from windstorms, according to a KPMG report.

(iv) Heatwaves and droughts have caused restricted water supply, damage to roads (for example, N15 in 2018), and increased demand in recreational areas.

(v) Four of the wettest years on record since 1954, have occurred in Sligo since 2000. Storm Clara caused 63mm of precipitation in one day, causing a major landslide in Castlebaldwin and flooding on the R293.

These challenges could be addressed through effective adaptation strategies, based in efficient data-monitoring and projections, cost-benefit analysis of ecosystem-based approaches, stakeholder engagement with adaptation strategies, an effective storm surge model coupled with a network of low-cost sensing technologies and more.

PROPOSED POLICY OPTIONS

The research conducted as part of the EU SCORE project's work at ATU Sligo has focused on more effective climate data monitoring through low-cost sensors and citizen science to understand the trends and impacts of coastal hazards; studying the role of ecosystem-based adaptation approaches in mitigating coastal hazards; and effective climate modelling and risk assessment through digital twin and early warning systems. The impacts, including strengths and weaknesses, of this research are highlighted in this section.

(1) EFFECTIVE CLIMATE MODELING AND RISK ASSESSMENT

Strengths:

- Enables accurate assessment of climate change impacts on Sligo's environment, infrastructure, and communities.
- Provides crucial data for developing climate adaptation and mitigation strategies.
- Supports evidence-based decision-making for policy development and urban planning.
- Enabling the development of early-warning system that will enable testing what-if conditions

Weaknesses:

- Requires specialized expertise and technological infrastructure for modeling and data analysis.
- Regular updates and monitoring are necessary to incorporate new climate data and research.

Examples of effective climate change modelling and monitoring activities that can be implemented for Sligo:

I. Coastal Erosion Modeling and Earth observations utilisation (Davis, E. 2015)

Strengths:

- Quantifies the historical and potential future rates of coastal erosion in Sligo, providing valuable insights into the vulnerability of coastal areas.
- Supports informed decision-making for coastal management, including beach nourishment, sediment management, and erosion control measures.
- Helps identify areas at high risk of erosion and prioritize intervention strategies.

Weaknesses:

- Requires detailed coastal topography data, coastal monitoring, and historical erosion records for accurate modeling.
- Uncertainties in predicting future erosion rates due to changing climate conditions and potential storm events.
- Requires an intensive technical task on the validation process.

Overcome Weaknesses

- Digital elevation models and LiDAR data capturing beach topography and coastal changes over time.
- Enhance data collection efforts through regular monitoring programs and advanced surveying techniques.
- Conduct sensitivity analyses to account for uncertainties and explore different climate scenarios for more robust modeling outcomes.

II. Coastal Flooding Modeling(Sligo County Council., 2016)

Strengths:

- Building on top on the OPW CFRAM project results by including the long-term sea-level rise component.
- Utilizes hydrodynamic modelling to assess the potential impacts of sea-level rise and storm surges on Sligo's coastal areas.
- Provides critical information for flood risk mapping, emergency response planning, and flood mitigation strategies.
- Enables the identification of vulnerable areas and the evaluation of different adaptation measures.

Weaknesses:

- Requires accurate elevation data, coastal bathymetry, and storm surge data for reliable modelling results.
- Uncertainties in predicting future sea-level rise rates and storm surge intensities.

Overcoming Weaknesses:

- Invest in high-resolution elevation data and coastal bathymetry surveys to improve accuracy in modelling.
- Incorporate probabilistic approaches and ensemble modelling techniques to account for uncertainties in sea-level rise and storm surge projections.
- Continuously update and refine models based on new data and scientific advancements.

III. Storm Surge Modeling

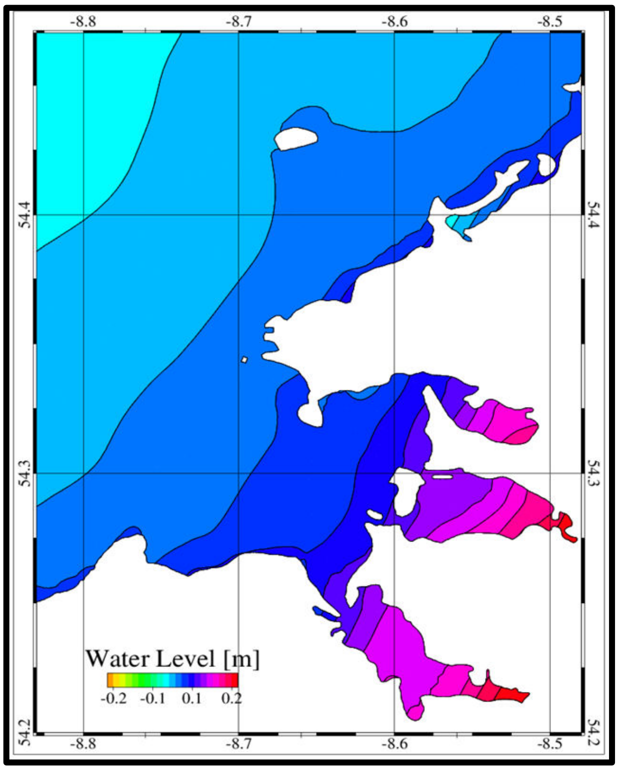

Figure 1: Water level simulated for a particular section of Sligo's domain using a finite element storm surge model.

Strengths:

- Supports the development of a storm surge model for the west coast of Ireland, specifically the northwest, with Sligo being a conducive site (Figure 1) as there is a dearth of studies focusing on the hydrodynamics in Donegal Bay given the vulnerability of many beaches and Islands in the region. .
- Assesses the potential impacts of extreme weather events and sea-level rise on Sligo's coastal areas.
- Provides crucial flood risk information for effective planning, emergency response, and infrastructure resilience.
- Identifies high-risk areas prone to storm surge inundation, aiding in the prioritization of mitigation strategies.

Weaknesses:

- Requires accurate coastal topography data, tidal records, and meteorological inputs for reliable modelling outcomes.
- Uncertainties in predicting storm characteristics, such as intensity, frequency, and track.
- Needs the support of coastal sensing technologies.

Overcoming Weaknesses:

- Collaborate with relevant stakeholders to gather and share accurate coastal data for improved modelling accuracy.
- Utilize ensemble modelling techniques to account for uncertainties in storm characteristics and their potential impacts.
- Validate the models using observed water level data and historical storm events to enhance reliability and performance.

IV. Integration of a Digital Twin Platform

Strengths:

- Enables real-time monitoring and visualization of environmental data, infrastructure performance, and socio-economic indicators.
- Enhances collaboration between stakeholders, facilitating informed decision-making and resource allocation.
- Provides a testing ground for scenario analysis and policy simulation, fostering innovation and resilience.

Weaknesses:

- Requires initial investment in technology infrastructure and data integration.
- Data privacy and security concerns must be addressed.

(2) ECOSYSTEM-BASED ADAPTATION

Ecosystem-based Adaptation (EBA) lies within the broader concept of Nature-based Solutions, which means to use natural ecosystems to address sustainable development goals, including water quality, biodiversity, climate change, socioeconomic opportunities, etc. In Sligo County, the role of for climate adaptation needs to be understood based on the local context, climate projections, and stakeholder perceptions. As part of this, the following EBAs have been studied through different methodologies:

I. Cost Benefit Analysis of Sand Dune Management

Strengths:

- This study is assessing the costs of implementing versus benefits from the EBA sand dune management (through marram grass planting, chestnut fencing etc) for reducing coastal erosion, in Streedagh, Enniscrone and Strandhill. We have found that sand dune management has reduced erosion in Streedagh and Enniscrone, and are in the process of validating our findings.
- This study helps quantify in monetary values the numerous benefits and co-benefits from sand dune management in the three sites, including biodiversity, carbon capture, job opportunities, property damage, recreational value of beaches, tourism, etc.
- This study can offer important insights on the role of sand dune management for mitigating coastal erosion based on satellite data on shoreline erosion and combined with sea-level rise and wind/wave data as factors that affect coastal erosion.
- This study can assess the different dune management strategies (for example, marram grass, chestnut fencing, no dune etc) for reducing coastal erosion and flooding, including hybrid options (ie combination of engineering and ecosystem-based adaptation)

Weaknesses:

- It can be difficult to gather all the necessary data for this study based on grey literature.
- This study focuses on a short ten-year time period, as sand dune management is a newly implemented EBA in the region.

II. Multi-Criteria Analysis of 8 EBAs with local stakeholders

Strengths:

- This study has been conducted for Sligo as part of the SCORE project by engaging with the local stakeholders. It offered important insights on the stakeholders' perceptions and acceptance of the eight existing/planned EBAs in Sligo County, as well as helped quantify the results in terms of ranks: **afforestation, wetland restoration, and peatland restoration being the top 3 EBAs to mitigate the impacts of floods, erosion and storms.**
- This study led to engaging and stimulating discussions amongst stakeholders from academia, public sector, industry, and civil society, involving them in the climate adaptation planning co-creation process.
- This study allowed stakeholders to rank the 8 EBAs (peatland restoration, wetland restoration, SUDS, afforestation, aquaculture, green roofs, rainwater and biodiversity parks, and sand dune management) based on 6 important evaluations criteria, including biodiversity, carbon capture, water quality, recreational opportunities, flood risk reduction, and job opportunity as well as feasibility criteria, such as technical feasibility, financial feasibility, ease of implementation, and stakeholder acceptability.

Weaknesses:

- This study was affected by the limited participation of stakeholders from the public sector, and this is being addressed through an online exercise for those stakeholders that couldn't attend in person.
- This study can be difficult to organise and coordinate, and it could be a better idea to go out to the stakeholders in the future rather than inviting them to a workshop.

III. Public Perception Analysis of Socioeconomic Vulnerability to Climate Risks and EBA's role in addressing them

Strengths:

- This study involves conducting individual interviews with the public in Sligo County. These interviews are assessing the public perceptions of climate risks in Sligo, their socioeconomic vulnerability in the face of climate risks, and the public perceptions/local knowledge of nature-based solutions and its role in increasing resilience. It can offer important insights on the socioeconomic vulnerability of Sligo's population to climate change, which can inform policy. The interviews will be conducted with communities expecting imminent flood risk (Coney Island and Raghly); communities whose livelihoods would be affected by climate change (farmers, fishermen, local businesses in Streedagh, Enniscrone, Strandhill etc); communities that are socioeconomically vulnerable to climate change (traveler communities, senior citizens, young people etc). We are in the process of interviewing 68 individuals, based on the sample size we have calculated.
- The data collected in this study would be analysed using Fuzzy Cognitive Mapping, which would be an illustration of the complex and detailed dynamics of public perceptions of climate risks and potential solutions in Sligo County. This mapping-based study of complex local contexts and dynamics to arrive to the most effective climate strategies can be replicable and scalable, in different parts of Ireland and Europe.
- This study can also assess the public perceptions of NBS's role in reducing climate risks as well as assessing their co-benefits, which can also inform local climate policy.

Weaknesses:

- This study could be affected by the sample size and quality.

IV. Coastal City Living Lab (CCLL) Model for EBA implementation

A Coastal City Living Lab (CCLL) is a real-life testing environment that will enable citizens and stakeholders to co-create and co-design the solutions with scientists, researchers and engineers to make sure they are accepted by society. The diagram below illustrates the coastal city living lab model.

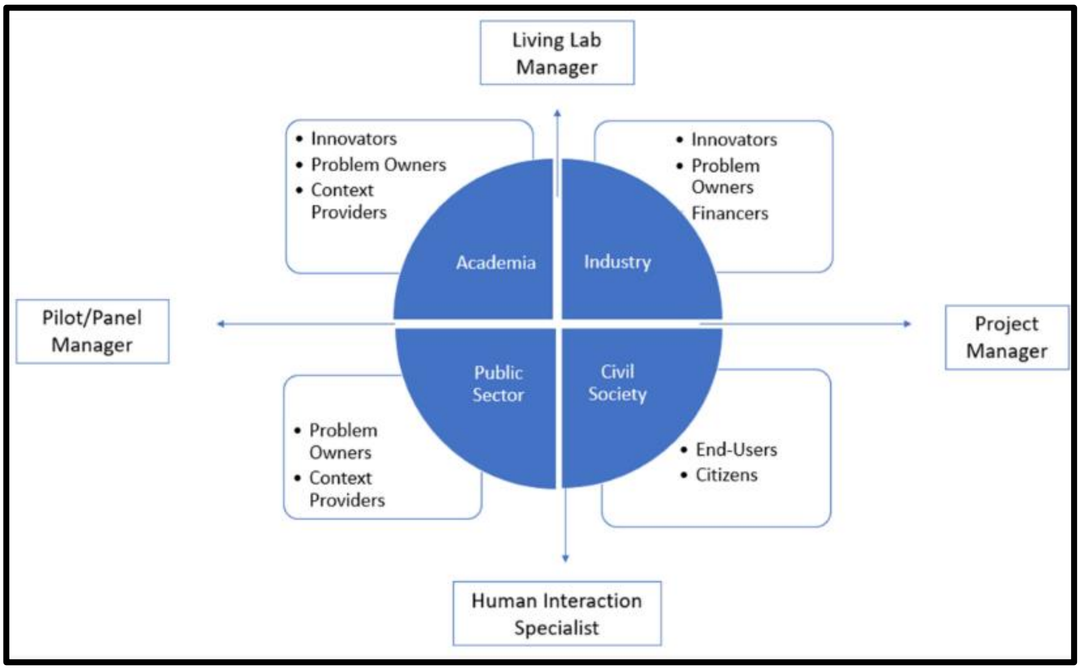

Figure 2 – Stakeholders in Coastal City Living Lab Model

Strengths:

- The CCLL model can address various barriers in EBA implementation (lack of dialogue, limited knowledge, low attention in the planning system etc)
- CCLLs can support collaborative governance, which is key to climate adaptation.
- CCLLs can aid decision-making in the face of climate uncertainty by bringing together interdisciplinary stakeholders.
- CCLLs can aid with scaling up EBA by providing a user-centric platform for knowledge-sharing.
- CCLLs can support the local demand for and community engagement in EBA schemes and provide a scalable and replicable model.
- CCLLs provide a platform for citizen to proactive engage in the co-creation and co-design process with EBA strategies.

Weaknesses:

- CCLL need resources, budget, time and expertise for implementation.
- EBA implementation within the CCLL model can be affected by the level and quality of stakeholder engagement.

V. Role of EBA in building socioeconomic and coastal resilience

Our research has found that coastal flood mitigation is one of the key motivations for implementing NBS, and its popularity has been growing due to its effectiveness and resilience in the face of storms and floods (Hanson et al., 2020). Numerous studies have indicated the relatively lower costs and flexibility of NBS compared to hard-engineering-based measures are contributing to their popularity (Brink et al., 2016). Whilst the use of NBS for coastal mitigation is rapidly increasing around the globe, their success depended on numerous factors and their effects are still difficult to monitor. In this context, the numerous monitoring tools being factors and their effects are still difficult to monitor. In this context, the monitoring tools being deployed and studies being conducted within SCORE can be particularly helpful.

Although research has been recognizing the importance of socio-economic co-benefits for the success of NBS projects, most of these projects still focused primarily on environmental agendas. One of the reasons for this is that it has not always been easy to quantify and address socioeconomic concerns (Santoro et al., 2019). We have found that NBS projects can contribute to 'triple-win' scenarios (ie environmental, social and economic wellbeing).

We have found that considering socio-economic indicators such as community demographics, education levels, income levels as well as cultural upbringing determine public perceptions of EBA and can influence the success of EBA implementation. Whilst EBA can be affected by people's perception, it can also act as an inclusive mechanism to address the challenges faced by marginalized groups much more effectively than engineering-based alternatives (Munang et al., 2013). EBA is specifically suitable for this purpose due to the high dependence of these groups on the local ecology for their livelihoods and can have multiple benefits for social empowerment (Woroniecki et al., 2019).

(3) CITIZEN SCIENCE ACTIVITIES AND LOW-COST SENSORS

Given the extensive storm damage caused to Sligo's beaches and islands (like Coney Islands) due to severe storm activities, the storm surge model developed by ATU Sligo would help better characterise these storms. The storm surge model can help quanitfy storm-induced induced erosion and identify high risk areas prone to coastal flood and erosion as a result of extreme sea levels. This will consequently facilitate the adoption of suitable adaptation options against storm damages. Deployment of low-cost water level sensors for real-time sea-level data, as well as to validate and calibrate the storm surge model is essential. The northwest of Ireland has had sparse coastal monitoring and this data can help setup a storm forecasting model to provide early warning support against severe storm surges in the immediate future.

Additionally it is now well known that many of Sligo's beaches are eroding. Thus, it is imperative to regularly monitor these beaches to quantify shoreline changes and volumetric changes to the sediment budget. Low-cost sensing technologies like aerial photographs from a kite aerial platform (Duffy et al.,2018), terrestrial photographs from coastsnap (Guisado-Pintado et al.,2020) etc will be deployed within a citizen science framework with a contributory and co-creation and participatory approaches as shown in Figure .

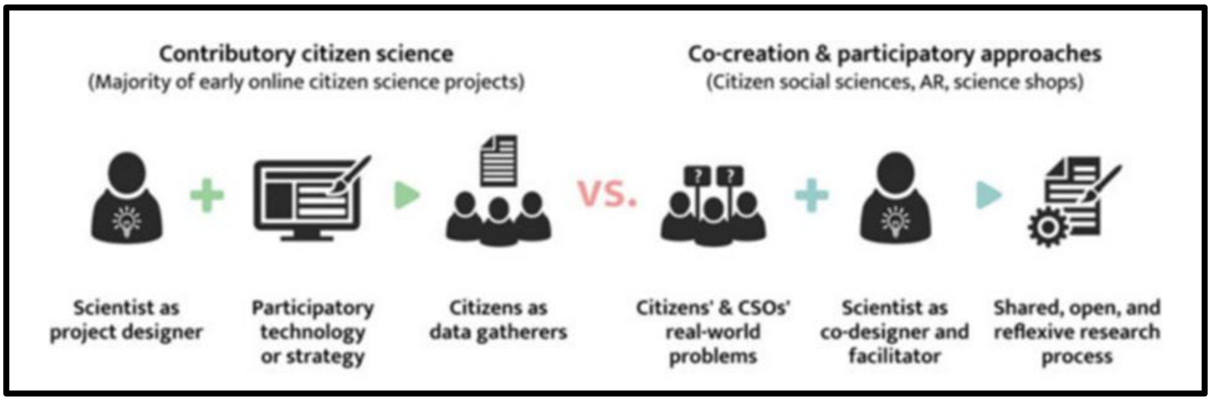

Figure 3: Contributory and co-creative approaches in science (Hidalgo et al. (2021))

As shown in Figure 4, various low-cost sensing technologies were found from a systematic literature review (Ahmed et al.,2023), as well as grey literature sources and the most suitable ones for citizen science activities for Sligo were chosen which includes sensing technologies like terrestrial/aerial photogrammetry and water level sensors as mentioned above.

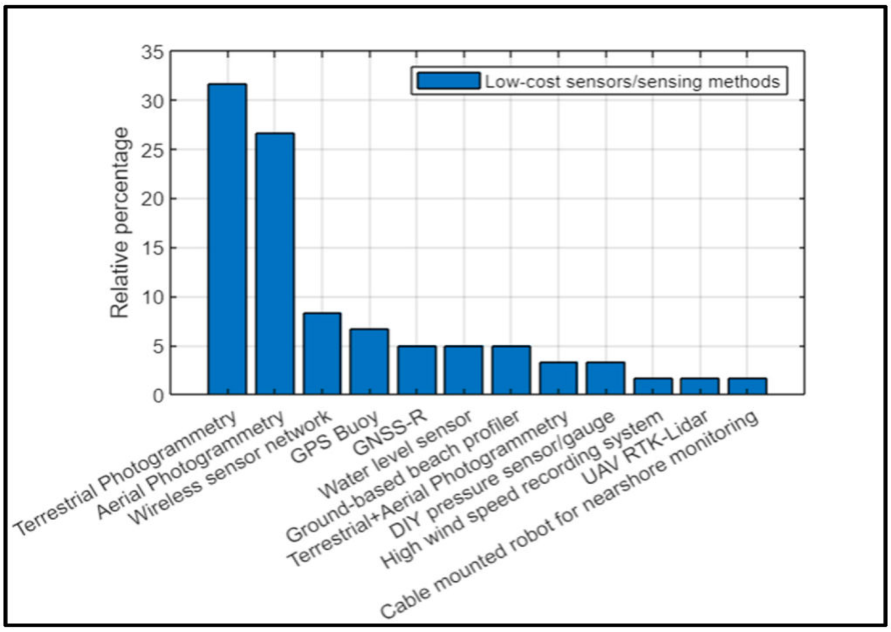

Figure 4: Percentage of the low-cost sensors/sensing methods (Ahmed et al.,2023)

These low-cost sensors will complement the data from institutional sensors, allowing to fill the spatial and temporal gaps and producing more solid coastal city early-warning systems. This can be better understood from Figure , where data gaps are evident from water level data recorded at the Sligo tide gauge. This can be overcome by deploying low-cost water level sensors which can often perform better than a conventional tide gauge (Spicer et al.,2021).

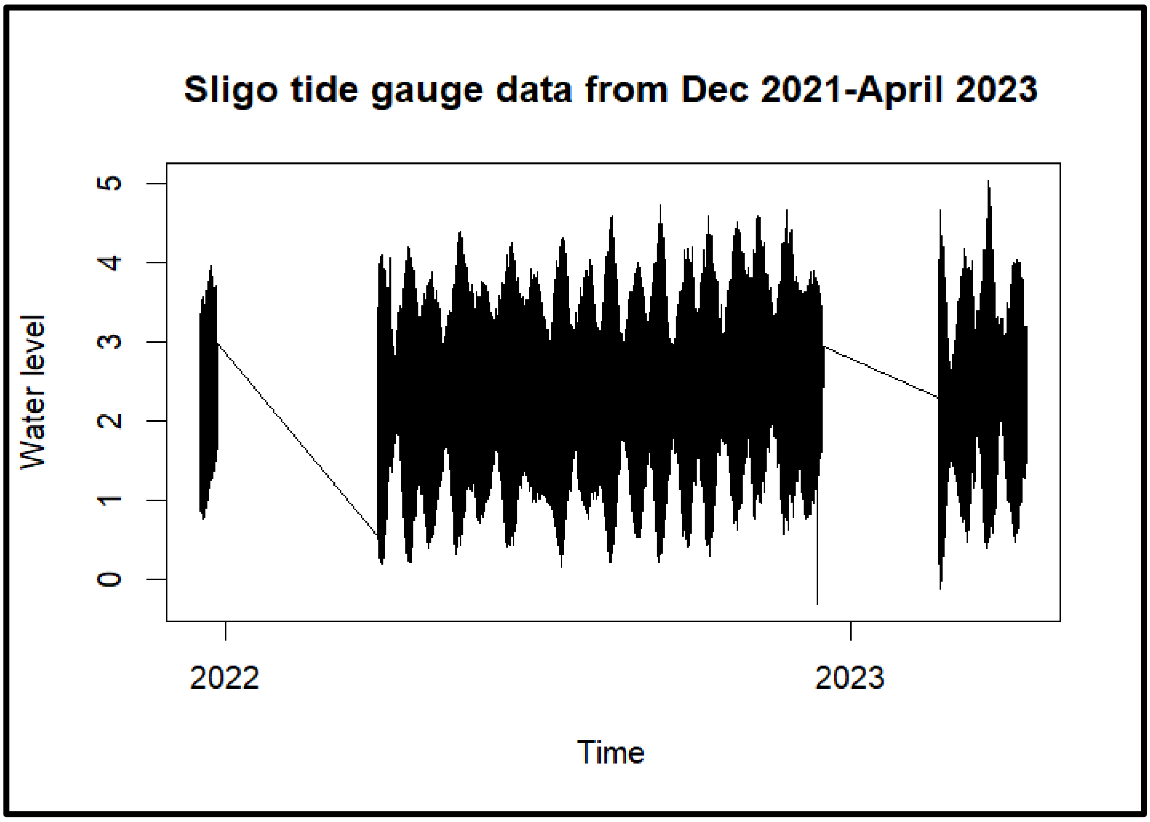

Figure 5: Water level data from the tide gauge at Sligo for the period from Dec 2021-April 2023

These low-cost sensors are used to monitor climate change-induced coastal hazards and also monitor the efficiency of the EBA. For instance, the aerial images from the kites could be used to evaluate whether dune management interventions have been efficient by comparing the aerial images over time.

Strengths:

- Citizen's engagement to co-monitor marine variables like sea level using water level sensors and coastal erosion using aerial platforms like kite for kite aerial photography
- Complementing the data from standard instruments and filling any data gaps from the standard instruments
- Empowering the citizens in the collection of coastal data and making them cognizant of the climate change impact on marine variables and the coast
- Evaluating the efficiency of the EBA's using these low-cost sensors.

Weaknesses:

- Damage to the sensors due to mishandling
- Poor data quality due to improper mounting and deployment of sensors
- Lack of citizens interest in long term monitoring efforts

Overcoming weaknesses:

- Citizen engagement through workshops and imparting proper training.
- Making the sensors data available in an online platform.

FINAL POLICY RECOMMENDATIONS

- The Coastal City Living Lab has been found to support ecosystem-based adaptation approaches as well as the process of co-creation of climate strategies through effective stakeholder engagement and gathering of local knowledge. The Sligo County Council could use all the knowledge generated within the CCLL to inform climate strategies.
- Low-cost sensor technologies have proven to be extremely effective in improving the efficiency of monitoring coastal climate data, which in turn can result in more effective climate models. The data from low-cost sensors can be pivotal in informing climate policy in Sligo County.
- The shoreline erosion analysis as well as other earth observation studies have provided important data, but can be validated through citizen science activities and arial images, which can be supported by the Sligo County Council.
- A dynamic storm surge model is being developed, and the results from it can contribute to creating a 3D digital model of Sligo County, to map climatic challenges, its effects on the population, as well as the impacts of climate strategies in real-time. These results can encourage the investment needed in infrastructural development to capture and implement the Digital Twin system, as well as support the Sligo County Council with decision-making through accurate data.
- The what-if scenarios being developed and tested by the integrated models in SCORE are supported by the local priorities and needs, using the CCLL model. This is innovative, and involves the final users of digital twin in an iterative process of co-creating the digital

twin. The Sligo County Council can help digital twin become user-friendly by ensuring user-participation.

- The EBA strategies considered for Sligo County have been adapted through the CCLL approach, based on stakeholder engagement through living lab workshops and tools like multi-criteria analysis. The results reflect the stakeholders' perceptions and needs (including stakeholders from academia, public sector, civil society, and industry). Afforestation, peatland restoration, and wetland restoration have been identified as the most effective EBAs for Sligo's context. The Sligo County Council could consider the implementation of these EBAs.
- The socioeconomic evaluation of adaptation strategies has been continuously monitored through multi-criteria analysis, cost-benefit analysis and a study of public perceptions using fuzzy cognitive mapping. These provide important insights on the role of climate adaptation strategies as well as their socioeconomic impacts, while establishing methodologies for their assessment. Communities in Raghly, Dunmoran, Enniscrone and Coney Island have particularly expressed their concern about sea-level rise, erosion, flood-risk and their willingness to engage with climate action as well as implementation of Nature-based Solutions. The Sligo County Council could support and engage with these communities.
- Through the CCLL, the community is continually involved in co-defining, co-creating, and co-designing activities for climate adaptation in Sligo County. The CCLL model established through the four years of SCORE will continue after the project, and can be supported by the Sligo County Council. The knowledge generated can be exchanged with other Irish cities and projects across Ireland and Europe, and the Sligo County Council can support this knowledge-exchange.

REFERENCES

Ahmed, T.; Creedon, L.; Gharbia, S.S. Low-Cost Sensors for Monitoring Coastal Climate Hazards: A Systematic Review and Meta-Analysis. Sensors 2023, 23, 1717. https://doi.org/10.3390/ s23031717

Brink, E.; Aalders, T.; Adam, D.; Feller, R.; Henselek, Y.; Hoffmann, A.; Ibe, K.; Matthey-Doret, A.; Meyer, M.; Negrut, N.L.; et al. Cascades of green: A review of ecosystem-based adaptation in urban areas. *Glob. Environ. Change Hum. Policy Dimens.* **2016**, *36*, 111–123.

Davis, E. A Spatial Study of Sites Susceptible to Coastal Erosion in County Sligo.

Duffy, J. P.; Shutler, J. D.; Witt, M. J.; DeBell, L.; Anderson, K. Tracking Fine-Scale Structural Changes in Coastal Dune Morphology Using Kite Aerial Photography and Uncertainty-Assessed Structure-from-Motion Photogrammetry. *Remote Sens.* **2018**, *10* (9). https://doi.org/10.3390/rs10091494.

Guisado-Pintado, E.; Jackson, D. W. T. Monitoring Cross-Shore Intertidal Beach Dynamics Using Oblique Time-Lapse Photography. *J. Coast. Res.* **2020**, *95* (sp1), 1106. https://doi.org/10.2112/SI95-215.1.

KPMG, 2023. Sligo County Council Climate Change Risk Assessment. Available here: KPMG_SligoCoCo_LACAP_May2023 (1).pdf

Munang, R.; Thiaw, I.; Alverson, K.; Mumba, M.; Liu, J.; Rivington, M. Climate change and Ecosystem-Based Adaptation: A new pragmatic approach to buffering climate change impacts. *Curr. Opin. Environ. Sustain.* **2013**, *5*, 67–71

Paul O'Connor, Conor Murphy, Tom Matthews, Robert L. Wilby, Relating drought indices to impacts reported in newspaper articles, International Journal of Climatology, 10.1002/joc.7946, 43, 4, (1796-1816), (2022).

Riaz, K., McAfee, M., & Gharbia, S. S. (2023). Management of Climate Resilience: Exploring the Potential of Digital Twin Technology, 3D City Modelling, and Early Warning Systems. Sensors, 23(5), 2659.

Santoro, S.; Pluchinotta, I.; Pagano, A.; Pengal, P.; Cokan, B.; Giordano, R. Assessing stakeholders' risk perception to promote Nature Based Solutions as flood protection strategies: The case of the Glinscica river (Slovenia). *Sci. Total Environ.* **2019**, *655*, 188–201

Sligo County Council. (2016). Coastal Flood and Erosion Risk Management Study - Rosses Point/Drumcliff Bay, IBE1062 Rev04, December 2016.

Spicer, P.; Schlichting, D.; Huguenard, K.; Roche, A. J.; Rickard, L. N. Sensing Storm Surge: A Framework for Establishing a Citizen Scientist Monitored Water Level Network. *Ocean Coast. Manag.* **2021**, *211*, 105802. https://doi.org/10.1016/j.ocecoaman.2021.105802.

Tiwari, A.; Rodrigues, L.C.; Lucy, F.E.; Gharbia, S. Building Climate Resilience in Coastal City Living Labs Using Ecosystem-Based Adaptation: A Systematic Review. *Sustainability* **2022**, *14*, 10863. https://doi.org/10.3390/su141710863

Woroniecki, S.; Warnsler, C.; Boyd, E. The promises and pitfalls of ecosystem-based adaptation to climate change as a vehicle for social empowerment. *Ecol. Soc.* **2019**, *24*, 13.

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