**Development Plan for CRISI: Climate Resilience Investment Scoring Intelligence for European Tourism under Climate Change**

**Introduction**

Climate change poses profound challenges to Europe’s tourism sector, which accounts for a substantial share of the economy and employment (roughly 10% of European jobs). Rising temperatures, changing precipitation, and more frequent extreme events are already altering travel patterns – for example, future warming scenarios suggest a **north–south shift** in tourism demand, with northern Europe likely to benefit from milder summers while southern Mediterranean destinations face declining summer appeal. These shifts could stress local economies that rely heavily on tourism, undermining growth and jobs. At the same time, investors and policymakers are increasingly aware of physical climate risks to long-term returns, spurring frameworks for climate-resilient investment strategies. However, recent research highlights critical gaps: there is **insufficient linkage between climate indicators and tourism demand, and a lack of decision-support tools for adaptation in tourism destinations**.

**CRISI** (Climate Resilience Investment Scoring Intelligence) is envisioned as an AI-powered tool to fill this gap – translating climate and economic data into actionable **resilience scores** for the tourism sector. The goal is to inform **macroeconomic investment policy** by identifying which regions, sub-sectors, or projects are most vulnerable or resilient under future climate scenarios, and to guide strategic investments in adaptation. The following plan outlines the structure of a PhD dissertation that will develop CRISI (covering research design, methodology, and validation) and the framework for the actual software tool (technical architecture, AI model, data pipeline, interface, and deployment). Emphasis is placed on methodological rigor, integration of expert knowledge, spatial-economic data analysis under climate scenarios, and relevance to policy makers and investors. The plan is scoped to be **achievable within a PhD timeframe** while laying a foundation expandable into an operational tool after the dissertation.

**PhD Dissertation Structure and Methodology**

**Chapter Plan**

* **Chapter 1: Introduction** – Presents the research problem and objectives of developing CRISI. It defines the scope (European tourism under climate change), formulates research questions, and establishes the significance for policy and investment. This chapter also overviews the climate change impacts on tourism (e.g. heatwaves, snow loss, sea-level rise) and the need for resilience investment, grounding the study in current policy contexts (EU climate adaptation strategy, tourism policy frameworks).
* **Chapter 2: Literature Review** – Reviews interdisciplinary literature on climate change and tourism, climate **risk assessment frameworks**, sustainable tourism and adaptation strategies, macroeconomic modeling of climate impacts, and applications of AI in climate risk or economic forecasting. A systematic review approach will be used, ensuring coverage of key studies and identifying gaps in knowledge. *(For example, a recent review finds an abundance of studies on climate risks to tourism but few addressing adaptive policy tools or linking climate metrics to tourism outcomesumu.diva-portal.org.)* This chapter will distill critical factors influencing tourism resilience and inform the conceptual framework for CRISI.
* **Chapter 3: Conceptual Framework & Methodology** – Develops the conceptual model underpinning CRISI. It defines how climate stressors, exposure, sensitivity, and adaptive capacity interact to affect tourism resilience. A diagram or framework (e.g. linking climate indicators to economic outcomes and resilience scores) will be presented. The chapter details the **research design** (which follows a design-science methodology for tool development), including hypotheses or propositions (e.g. “climate suitability index declines correlate with drops in tourist arrivals”) and an overview of the methodological steps. Key components of the methodology are introduced here: data collection plan, modeling approach, and the integration of expert input (Delphi method).
* **Chapter 4: Data Collection and Indicator Development** – Describes the data used and the creation of relevant indicators. This includes **spatial climate data** (projected temperature, precipitation, extreme events, etc.), **tourism statistics** (tourist arrivals, overnights, tourism revenue/GDP by region), and other socio-economic data (employment, infrastructure, and adaptive capacity indicators). Data sources (e.g. European Climate Data Store, Eurostat, national tourism boards) and the timeframes/scenarios (e.g. 2030, 2050 under RCP4.5 and RCP8.5) are specified. The chapter documents how raw data are processed into indicators like a *Tourism Climate Index* or *heatwave days per summer*, which serve as inputs to the model. It also addresses data quality, resolution (e.g. aggregating climate model outputs to the regional level), and any limitations (such as gaps or uncertainties in projections). The outcome is a catalogue of **climate-risk indicators and economic variables** that will feed into the scoring model.
* **Chapter 5: Model Development – AI-Powered Scoring System** – Chronicles the development of the CRISI scoring model. The chapter first elaborates the chosen modeling techniques – for instance, a combination of machine learning and statistical analysis to link climate conditions to tourism performance. A likely approach is to train a predictive model (e.g. panel regression or a Random Forest) on historical data to quantify how climate variability (temperature, snow cover, etc.) has affected tourist demand across regions. The model is then used to project future impacts under various climate scenarios, yielding projected changes in tourism metrics (e.g. % change in visitor numbers or revenue). These projections, combined with factors like a destination’s economic reliance on tourism and existing adaptive measures, are translated into a **resilience score** (e.g. a composite index where higher scores mean more climate-resilient or lower risk). The scoring methodology (how indicators are weighted and aggregated) is detailed and justified – potentially using a multi-criteria decision approach. Importantly, this chapter reports on iterative model refinement: initial results are obtained, then calibrated or adjusted through expert feedback (from the Delphi study) to ensure realism and policy relevance. Model performance evaluation (goodness of fit, error metrics in cross-validation) is also documented here as evidence of methodological rigor.
* **Chapter 6: Expert Elicitation via Delphi Method** – Documents the integration of expert knowledge using the Delphi technique. It describes how a panel of experts (e.g. climate scientists, tourism industry experts, policy makers, investment analysts) is recruited and how the Delphi rounds are conducted. In Round 1, experts might be asked to identify and rank the most critical factors for tourism resilience under climate change, or to evaluate the preliminary set of indicators and scoring criteria. In Round 2 (and possibly Round 3), experts review aggregated feedback and refine their inputs towards a consensus on key indicators and their weightings or threshold values. This chapter will present the outcomes of the Delphi study – for example, consensus on the relative importance of factors (such as water availability, coastal flood risk, or diversification of tourism offerings) in the resilience score. The Delphi results directly inform the model (Chapter 5) by providing a validated basis for weighting and selecting indicators. Using expert elicitation in this way strengthens the tool’s credibility and relevance; it mirrors prior studies that used Delphi panels to gather tourism-climate expertise. The chapter will also reflect on the process (e.g. level of agreement achieved, lessons learned about expert perceptions).
* **Chapter 7: Case Studies and Validation** – Demonstrates and validates the CRISI tool through real-world applications. Several **case studies** are presented, such as applying the tool to different types of destinations (e.g. a Mediterranean coastal region, an Alpine winter ski region, an urban cultural city). For each case, the chapter describes the context (climate threats and tourism profile), runs the CRISI assessment, and presents the resulting resilience score and insights. These case studies serve to illustrate how CRISI can guide decision-making – for instance, by revealing that a coastal region’s score deteriorates significantly under a high sea-level rise scenario, indicating urgent need for investment in protective infrastructure or diversification. Validation is approached from multiple angles: **quantitative validation** (comparing model predictions to historical outcomes or known events, and performing statistical cross-validation) and **qualitative validation** (presenting results to local experts or stakeholders for review). The chapter may include an expert review workshop where stakeholders from the case study regions evaluate whether the CRISI outputs align with on-the-ground realities, providing an additional feedback loop to refine the model. Any discrepancies or limitations uncovered during validation are discussed, and the overall performance and reliability of the tool are assessed.
* **Chapter 8: Discussion and Conclusion** – Interprets the findings and their implications for both theory and practice. This chapter discusses how the CRISI development has advanced academic knowledge (e.g. new insights into climate-economic modeling for tourism, the efficacy of combining AI with expert input) and addresses the initial research questions. It highlights the policy and investor relevance of the results – for example, how the scoring system can be used by national tourism authorities or investment banks to prioritize climate-resilient projects. The chapter connects back to literature, explaining how the tool fills the identified gaps (providing the missing link between climate indicators and tourism impacts, and offering a concrete adaptation decision-support toolumu.diva-portal.org). It also critically examines limitations (data uncertainty, model assumptions, scope restricted to Europe, etc.) and suggests future work to extend the tool (such as incorporating more nuanced socio-economic factors, or expanding to other regions or sectors). Finally, a roadmap is proposed for transitioning CRISI from a PhD project into an **operational tool**, including steps for further testing, stakeholder engagement, and scaling up (e.g. securing collaborations or funding to maintain and update the tool). The conclusion reinforces the importance of proactive climate resilience planning in tourism and the value added by an intelligence tool like CRISI in steering investments toward sustainable outcomes.

**Data Collection and Modeling Methodology**

To ensure methodological rigor, the dissertation will employ a **comprehensive data collection and modeling strategy**:

* **Multi-Source Data Integration:** The research will compile a rich dataset combining **climate data** and **economic data**. Climate variables (e.g. temperature, heatwave days, precipitation, drought indices, snowfall, sea-level rise projections) will be sourced from high-resolution projections (such as the EURO-CORDEX regional climate models) for multiple scenarios (e.g. a moderate and a high-emission scenario). Tourism and economic data (e.g. international arrivals, tourism expenditure, contribution of tourism to regional GDP, number of tourism establishments) will come from sources like Eurostat, national statistical agencies, and industry reports. All data will be geo-referenced (by destination or region), enabling spatial analysis. Care will be taken to align data in space and time – for example, aggregating climate model outputs to the administrative regions used for tourism stats, and using consistent baseline periods for climate and tourism trends.
* **Development of Climate-Tourism Indicators:** Using the raw data, a set of **indicators** will be derived to quantify climate impacts on tourism. This may include established metrics like the *Tourism Climate Index (TCI)* or the *Holiday Climate Index*, which synthesize temperature, humidity, rain, and sunshine into a single “climate comfort” score for tourism[adaptecca.es](https://adaptecca.es/sites/default/files/documentos/2023-jrc-regional-impact-cc-european_tourism-demand.pdf#:~:text=the%20effect%20of%20current%20climatic,under%20two%20emissions%20pathways). Other indicators might be tailored to specific tourism activities (e.g. an index of snow reliability for ski tourism, or a beach suitability index considering temperature and water conditions). If not already available, such indicators will be computed following methods in the literature. (Notably, the Copernicus Climate Change Service has developed pan-European tourism climate indicators – such as indices for beach and urban tourism suitability – which can be leveraged[visitzagrebcounty.hr](https://visitzagrebcounty.hr/en/odrzivi-turizam-u-zagrebackoj-zupaniji-izazovi-i-prilike-u-doba-klimatskih-promjena/#:~:text=Interreg%20Euro).) Socio-economic indicators will measure **exposure and adaptive capacity** – for instance, the share of local employment in tourism (high values imply greater economic sensitivity to climate impacts) or the presence of adaptation measures (like percentage of tourism infrastructure with climate-proof design, if data can be obtained). The methodology will document how each indicator is calculated and justified, ensuring transparency in the scoring system.
* **Modeling Approach:** The core analytical approach is to model the relationship between climate conditions and tourism performance, then apply this relationship to future scenarios. The dissertation will likely use a **hybrid modeling** approach:
  + A **statistical or machine learning model** (such as multiple regression, random forest, or Bayesian model) will be trained on historical data to **estimate the impact of climate variability on tourism demand**. For example, using panel data of European regions over the past few decades, the model might regress tourism arrivals or revenues on climate indicators (TCI, number of extreme heat days, snow days, etc.), controlling for other factors (GDP growth, population, etc.). This reveals the sensitivity of tourism to climate factors (e.g. quantifying how a decrease in summer climate comfort correlates with fewer tourists). The model selection will balance accuracy with interpretability – given the policy focus, methods that provide clear insights (coefficients or feature importances) are preferred. Model validation will be done via cross-validation and out-of-sample tests to ensure it generalizes well.
  + The calibrated model is then used in a **scenario simulation**: feeding in projected future climate indicator values (for say 2030, 2050) to predict changes in tourism metrics for each region. This produces a **spatially explicit forecast** of which areas stand to lose or gain tourism activity under climate change. As prior research suggests, a pattern of **losses in southern Europe and gains in parts of northern Europe** may emerge – the model will quantify these shifts, including seasonal changes (e.g. shorter ski seasons, longer warm-weather seasons). The uncertainty across scenarios and climate models will be noted (e.g. using a range or ensemble of model outputs rather than a single projection).
  + **Resilience Scoring Algorithm:** Building on the scenario results and additional factors, an algorithm will compute the **CRISI score** for each case (region, country, or investment project). The score could be a composite index (normalized to a convenient scale, say 0–100 or a letter grade) that reflects **climate resilience or risk level**. The methodology for this index will combine *exposure* (the magnitude of projected climate impact on tourism demand) with *sensitivity* (economic dependence on tourism and any fragilities) and *adaptive capacity* (measures in place to cope or diversify). For instance, a region with a large projected drop in tourist income and a high dependence on tourism, but that has not invested in adaptation, would score as high risk (low resilience). In contrast, a region with minor climate impacts or successful adaptation strategies would score more favorably. If appropriate, **weightings** for each component of the score will be determined – initially based on literature and data, and then refined through Delphi expert input. The result is a systematic, reproducible way to rank or evaluate tourism regions by climate resilience, which will be at the heart of the CRISI tool.
* **Expert Integration in Modeling:** Throughout the modeling process, expert knowledge (via the Delphi panel) will guide key choices. For example, experts might suggest additional variables to include (such as water security or insurance coverage), validate the plausibility of model outputs, or adjust the importance of certain criteria. This ensures the model is not a “black box” detached from reality, but rather aligned with domain expertise. The methodology will explicitly incorporate an **iterative loop**: initial model -> expert feedback -> model refinement. This co-design ethos mirrors best practices in climate services tool development[meetingorganizer.copernicus.org](https://meetingorganizer.copernicus.org/EGU25/EGU25-9114.html?pdf#:~:text=need%20for%20locally%20focused%20adaptation,evaluate%20local%20climate%20risks%20and), where stakeholder input is used to tailor indicators and outputs for practical decision-making.
* **Ensuring Rigor and Transparency:** Methodological rigor is maintained by documenting each step clearly and using established techniques. A **literature-backed rationale** will accompany each methodological choice (e.g. citing why a certain index is used or why a particular ML algorithm is suitable). Uncertainty will be accounted for by examining multiple scenarios and performing sensitivity analysis (e.g. how does the resilience ranking change if we weight economic vs. environmental factors differently?). All data transformations and model parameters will be made transparent (possibly in appendices or open-source code), allowing other researchers or practitioners to reproduce and trust the findings. By the end of the methodology phase, we expect to have a robust model that integrates climate and economic data to output a defensible resilience score – the foundation for the CRISI tool.

**Literature Review Strategy**

Conducting a thorough literature review will be critical to ground the CRISI project in existing knowledge. The strategy for the literature review includes:

* **Define Key Themes and Scope:** The review will cover several intersecting domains:
  1. *Climate Change Impacts on Tourism* – studies quantifying how climate variability and extreme events affect tourist behavior, destination viability (e.g. ski tourism under warming, coastal tourism and sea-level rise). This includes IPCC reports and regional assessments for Europe (such as the European Climate Risk Assessment highlighting tourism risks like reduced snow or heat stress[climate-adapt.eea.europa.eu](https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies/tourism#:~:text=snow%20cover%2C%20increases%20and%20prolongs,water%20scarcity%20in%20southern%20Europe)[climate-adapt.eea.europa.eu](https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies/tourism#:~:text=Winter%20tourism%20has%20been%20identified,in%20central%20and%20southern%20Europe)).
  2. *Tourism Adaptation and Resilience* – literature on how destinations and policymakers are responding (e.g. diversification strategies, technological adaptations, policy frameworks for climate adaptation in tourism). Reports from OECD, UNWTO, European Commission (Climate-ADAPT case studies) will be reviewed to gather best practices and policy recommendations.
  3. *Investment and Macroeconomic Perspectives* – research on the economic impacts of climate change (especially on regional economies) and how investment decisions incorporate climate risk. This includes frameworks like climate risk disclosure (TCFD) and initiatives for climate-resilient investment portfolios[iigcc.org](https://www.iigcc.org/resources/consultation-climate-resilience-investment-framework#:~:text=The%20Climate%20Resilience%20Investment%20Framework,and%20the%20wider%20financial%20ecosystem), as well as any studies on tourism investment under climate uncertainty.
  4. *Methodological Approaches* – previous attempts to create indices or models for climate risk/resilience (e.g. vulnerability indices, multi-criteria analysis in tourism or regional planning) and the use of **AI/Machine Learning** in climate and economic modeling. For instance, exploring how AI has been used for demand forecasting in tourism or for analyzing climate risks. This ensures the project builds on state-of-the-art methods and identifies suitable techniques.
* **Systematic Search and Review:** A systematic search will be undertaken in academic databases (Scopus, Web of Science, Google Scholar) using relevant keywords (e.g. *“tourism climate change Europe”*, *“tourism adaptation policy”*, *“climate risk index tourism”*, *“machine learning climate risk”*, etc.). Inclusion criteria will focus on studies from roughly the past 10–15 years, plus any seminal earlier works. The search will also cover grey literature (EU project reports, industry white papers) for practical insights. The review process will involve cataloguing and thematically organizing the literature. If feasible, a literature matrix or concept map will be created to identify consensus, contradictions, and gaps across studies. A recent systematic review on climate and carbon risk in European tourismumu.diva-portal.org will serve as a starting point, helping to pinpoint what has been covered extensively versus what remains under-explored. Notably, that review highlighted gaps such as the lack of integrated studies on climate impacts and adaptation in tourismumu.diva-portal.org – which directly motivates the CRISI research.
* **Critical Synthesis:** Rather than just summarizing sources, the literature review will critically synthesize findings. For example, it will compare projected climate impacts from different studies (do all agree that alpine ski resorts face severe decline by mid-century?), evaluate the success of adaptation measures documented in case studies, and examine how different frameworks define “resilience.” It will also draw lessons on methodology: e.g., what indicators have others used to measure climate risk in tourism, and how effective were they? The synthesis will identify best practices and inform the design of CRISI (for instance, adopting a proven indicator or avoiding pitfalls noted by previous authors). Contradictions or uncertainties in the literature will be noted as areas where expert elicitation might be needed to reach clarity.
* **Outcome – Knowledge Gaps and Framework:** The literature review will conclude by explicitly stating the knowledge gaps and how the PhD will address them. For instance, if few studies link **spatial climate data with economic outcomes** at the regional level, CRISI’s modeling will tackle that. If no existing tool provides an investment-oriented scoring for tourism resilience, CRISI’s development becomes clearly justified. By mapping out the current knowledge, the review will ensure the dissertation is **positioned at the cutting edge**, avoiding duplication and focusing on innovation. It will also justify the inclusion of certain variables or approaches in the methodology (backed by literature support). Overall, this strategy ensures the PhD research is deeply informed by and contributes back to the scholarly and policy discourse on climate-resilient tourism.

**Expert Elicitation via Delphi Method**

Integrating expert judgment is a cornerstone of the CRISI development to enhance its relevance and credibility. The Delphi method will be employed as follows:

* **Purpose of Delphi Integration:** Experts will help identify which factors truly matter for climate resilience in tourism and validate the weightings/thresholds used in the scoring model. While data-driven methods can reveal correlations, expert insight is crucial for capturing nuances (e.g. emerging risks not evident in historical data, or feasibility of adaptation actions) and for ensuring the tool’s outputs make sense in a real-world context. The Delphi method provides a structured way to harness collective intelligence and achieve consensus on these issues.
* **Panel Composition:** A diverse panel of ~15–20 experts will be assembled, drawing from academia, industry, and government. This may include climate scientists with knowledge of regional impacts, tourism scholars, policy makers from tourism or environment ministries, leaders from tourism industry associations, and investors or development bank experts focused on climate risk. The diversity ensures that all perspectives (scientific, economic, practical) inform the scoring system. Experts will participate anonymously (to reduce dominance and bias), which is a key Delphi principle.
* **Delphi Rounds Design:** Two to three rounds of questionnaires are envisioned:
  + *Round 1:* This round will gather initial inputs on what factors and criteria should be included in the CRISI scoring, and how they should be weighted. For example, experts might be asked: “List the top 5 indicators that you believe determine a tourism destination’s climate resilience,” or “On a scale, rate the importance of factors such as **infrastructure robustness, climate projections, tourism dependence, adaptive capacity** in assessing resilience.” Open-ended questions will allow experts to suggest additional indicators or considerations that the literature or model might have missed. The responses will be aggregated and analyzed to identify common themes and any divergent views.
  + *Round 2:* A structured questionnaire is sent, feeding back the summarized results of Round 1. Experts might be asked to reconsider their judgments in light of group feedback – for instance, if Round 1 showed consensus on certain top factors but disagreement on others, Round 2 could ask experts to rank the refined list of factors or agree on weights (like what percentage importance to assign to climate exposure vs. adaptive capacity in the score). This round could also present some preliminary model outputs (e.g. a trial resilience score for a sample region) and ask experts if the results seem plausible or how they would adjust them. The goal is to move toward convergence on key points.
  + *Round 3 (if needed):* If critical issues remain unresolved (say, experts are split on the weight of a particular indicator), a final round can be conducted focusing on those specific points. By now, areas of agreement will be solidified and any remaining outliers can be discussed. Alternatively, the process might stop at Round 2 if sufficient consensus is achieved.
* **Utilizing Delphi Outcomes:** The consensus from the Delphi panel will directly inform the design of CRISI:
  + **Indicator Selection:** Indicators that are consistently ranked as important by experts will be prioritized in the model. Conversely, if experts indicate that certain data-driven indicators are misleading or less critical, those might be adjusted or dropped. For example, experts might emphasize that *water availability* is a crucial resilience factor for Mediterranean destinations, prompting the inclusion of a water stress index in the data if not already considered.
  + **Weighting Scheme:** Delphi results will provide a rationale for the weighting of components in the resilience score. If experts collectively believe that “adaptive capacity” (like disaster preparedness plans, diversification) should count for, say, 40% of the score’s weight, whereas exposure (projected climate impact) is 60%, then the scoring algorithm will reflect that. This grounds the model in expert stakeholder values rather than arbitrary choices.
  + **Thresholds and Rating Categories:** Experts may also help define what constitutes a “high” vs “low” resilience score. Through Delphi feedback, we might establish qualitative descriptions – e.g., a score above a certain number means the destination is likely resilient with minor adaptation needs, whereas a low score signals urgent intervention needed. Their input ensures these categories make intuitive sense to end-users.
* **Quality Control and Iteration:** Throughout the Delphi process, careful attention will be paid to question design (to avoid ambiguity) and analysis of responses. The research team will act as facilitators, summarizing and feeding back information between rounds without imposing their own bias. All Delphi communications and results will be documented. If the expert panel raises new concerns or ideas beyond the initial scope, the research methodology is flexible to accommodate them – for instance, adding a variable to the model or planning a follow-up interview for deeper discussion. This adaptive approach echoes a **participatory co-creation** process, similar to other climate service tool developments that engaged stakeholders to tailor outputs[meetingorganizer.copernicus.org](https://meetingorganizer.copernicus.org/EGU25/EGU25-9114.html?pdf#:~:text=need%20for%20locally%20focused%20adaptation,evaluate%20local%20climate%20risks%20and).
* **Integration with PhD Timeline:** The Delphi study will be timed such that its outcomes can be incorporated before finalizing the model and conducting case studies. Likely, it will occur mid-project (e.g. in the second year of the PhD) after preliminary data analysis is done but in time to tweak the model construction. The expert engagement not only strengthens the dissertation’s findings but also builds a network of supporters and potential users for the eventual tool (some panelists could become early adopters of CRISI or champions in their organizations). Overall, the Delphi integration ensures that **CRISI’s methodology is vetted by experts and the resulting tool is grounded in consensus knowledge**, enhancing its legitimacy and usefulness.

**Software/Tool Development Framework**

While the PhD will produce the conceptual and analytical core of CRISI, an equally important aspect is planning the **practical software tool** that operationalizes these ideas. Below is a detailed framework for developing the CRISI software, covering the system architecture, AI model design, data pipeline, user interface, and deployment strategy. This plan is structured to produce a functional prototype during the PhD, with a vision for scaling it up post-PhD for broader use.

**Technical Architecture**

The CRISI tool will be built with a **modular, layered architecture** to ensure flexibility and scalability:

* **Data Layer:** At the base, a data layer will handle storage and management of the diverse datasets. This may involve a combination of databases:
  + A **spatial database** (e.g. PostGIS) to store geospatial data like regional boundaries, maps, and spatially-referenced climate indicators.
  + A **time-series database or data warehouse** for climate projections and tourism/economic time series. For performance, processed indicators (such as annual tourism climate index values per region, or scenario projections of tourist numbers) might be stored so that the tool can quickly retrieve and query them. This layer will also include metadata and documentation for each dataset. Access to raw data (like large climate model outputs) might remain external (hosted on climate data servers), but the architecture will fetch and cache only the needed summary indicators to keep the application efficient.
  + Data update mechanisms will be in place: for example, scripts to periodically update tourism statistics (yearly) or incorporate new climate scenario runs when available. The data layer will thus support both **static analysis** for the dissertation and dynamic updates for the live tool.
* **Processing & Analytics Layer:** This middle layer contains the business logic – essentially the **CRISI analytical engine**. Key components include:
  + The **AI/ML Model Component**: the trained model (from the PhD research) will be implemented here, possibly as a set of functions or microservices. For example, a service that, given a region and scenario, computes the expected change in tourism demand (using the regression/ML model) and then computes the resilience score based on that and other inputs. This component might be built in Python (leveraging libraries like scikit-learn or PyTorch for any machine learning) and exposed via an API for the front-end to call.
  + The **Scoring Engine**: logic to combine different indicators and apply the weighting rules (as determined by the methodology/Delphi). This could be a separate module that ensures the formula for the resilience score is applied consistently for any input data.
  + **Geospatial Analysis Module**: if the tool allows custom queries (e.g. drawing a new area on a map or selecting a specific locality), this module handles aggregating or interpolating data to that custom region. It might use GIS functions (possibly leveraging existing libraries or services).
  + **Scenario Management**: the tool will allow switching between scenarios (e.g. optimistic vs pessimistic climate outcomes, or near-term vs long-term). The processing layer will include configuration or lookup for scenario parameters (like which climate dataset to use for RCP4.5 2050 vs RCP8.5 2100). This ensures the computations are scenario-aware.
  + All these components will be designed with an **API-first approach**, meaning they can be accessed through well-defined interfaces. This not only aids the current tool’s front-end but also allows future integration (e.g. if down the line someone wants to plug CRISI’s engine into another platform or a command-line tool).
* **Application Layer (User Interface):** The top layer is the user-facing application. The architecture will likely be a web-based dashboard, given the need for interactive maps and broad accessibility (users just need a browser). The UI layer will interact with the processing layer via API calls:
  + The **web framework** could be something modern like a JavaScript framework (e.g. React or Angular) for a responsive single-page application. This will handle rendering the visualizations, maps, and forms for user input (like selecting a region or scenario).
  + A **mapping component** (leveraging libraries like Leaflet or Mapbox GL) to display geographic information. Users should be able to click on a country/region to see its score and related data. Heatmaps or choropleth layers will show resilience scores across Europe at a glance (e.g. color-coding regions by risk level).
  + **Charts and Tables** to present detailed data when a user drills down (for instance, a time-series graph of projected tourism revenue under different scenarios, or a breakdown of the score components – exposure vs. capacity – for a selected region).
  + The application layer will also incorporate **user input interfaces**: for example, filters to choose scenario or future time period, or toggles to apply certain adaptation assumptions (if applicable, e.g. “what if adaptation X is implemented – recalc score”). Initially, these might be simple, but the design will consider extensibility (like adding a feature for users to input their own data or to adjust weights in a sandbox mode for educational use).
  + Basic **user management** might be included if needed (e.g. if we restrict certain advanced features to expert users or allow saving custom scenarios). However, in a prototype, this may be minimal.
* **Integration & Workflow:** The three layers will work together as follows: when a user makes a request (say, “show me 2050 high-risk areas”), the UI triggers an API call to the processing layer specifying the scenario and query. The processing layer fetches necessary data from the data layer (or uses cached results), runs the model calculation and scoring, then returns the results (scores, data points) to the UI to visualize. This separation ensures that heavy computations happen server-side, and the client experience remains smooth. The architecture will be documented with a flow diagram (from input to output) for clarity.
* **Modularity and Extensibility:** By keeping data, logic, and presentation decoupled, we ensure that each part can be modified or upgraded independently. For example, if a new improved model is developed after the PhD, it can replace the AI component without overhauling the whole system. Or if a decision is made to integrate CRISI into an existing policy platform, one could bypass the custom UI and call the API from that platform. Similarly, the data layer can be expanded to new regions (even beyond Europe) and the processing layer would handle them as long as data is in the expected format. This modular design is crucial for scaling the tool from a prototype to an operational system used by multiple stakeholders.

**AI Model Design**

The AI/modeling component is the analytical heart of CRISI. Its design will emphasize both **predictive power** and **interpretability** to satisfy the needs of investors and policymakers. Key design elements include:

* **Model Objectives:** The model essentially has two tasks: (1) **Estimate Impact** – predict how climatic changes will affect tourism performance (demand, revenue, etc.) for a given region; (2) **Generate Score** – transform those impacts, along with other factors, into a composite resilience score. The AI design will ensure these tasks are well-served, possibly by using a combination of models or steps (one for prediction, one for scoring).
* **Choice of Algorithms:** Based on the data and problem structure, likely algorithm choices are:
  + For predicting tourism impacts: a **regression-based approach** (could be traditional linear regression, or a more flexible machine learning regression like Random Forests or Gradient Boosted Trees) that can handle nonlinear relationships and interactions (e.g. the effect of temperature on tourism might not be linear and could interact with whether a destination is coastal or mountain). If data volume is large and complex, machine learning models are helpful. However, **interpretability** is key – thus, methods like Random Forests would be accompanied by techniques like feature importance analysis or SHAP values to explain which climate factors are driving the predictions. Alternatively, a panel econometric model (fixed effects, etc.) could be used for interpretability but might be less predictive; the final design will weigh this trade-off.
  + For the resilience scoring: this might not require a separate “AI” if it is a formulaic index. But if determining the optimal weighting of components is complex, an AI approach like **multi-objective optimization** or even a simple neural network could theoretically assign weights. However, given the need for clarity, it’s more likely the weights come from Delphi consensus and are hard-coded or adjustable by the user, rather than learned by a black-box AI. The focus is on transparency here – users should be able to see how the score was calculated from the inputs.
* **Incorporating Spatial and Contextual Factors:** One challenge is that different regions have inherently different contexts (a 2°C temperature rise means something different in Finland than in Spain). The model design will handle this by including contextual features. For example, **regional typologies** (coastal, urban, alpine, rural etc.) might be encoded as features or by building separate sub-models for different region types, as done in some studies[adaptecca.es](https://adaptecca.es/sites/default/files/documentos/2023-jrc-regional-impact-cc-european_tourism-demand.pdf#:~:text=the%20effect%20of%20current%20climatic,under%20two%20emissions%20pathways). The model could first classify a region’s type (maybe via clustering or predefined categories), and then apply coefficients specific to that category. This ensures more accurate and realistic predictions.
* **Training and Validation:** The model will be trained on historical data (e.g. the past 20–30 years) where both climate variables and tourism data are available. Standard training-validation splits will be used, keeping some data out for testing. Given the temporal and spatial nature, a **cross-validation strategy** might involve a combination of time-based splits (e.g. train on earlier years, test on later years to see if it predicts future changes) and spatial splits (train on a subset of regions, test on others, to ensure it’s not overfit to specific locations). The model’s performance metrics (R², RMSE for regression, etc.) will be tracked. We expect the model to capture broad patterns (like the decline in low-altitude ski resorts with less snow) and will verify that it does so by comparing predictions with known trends. Any shortcomings (like if the model underestimates impacts of extreme events because they are rare in training data) will be addressed, possibly by incorporating synthetic data or additional variables for extremes.
* **Uncertainty and Ensemble Modeling:** Climate projections come with uncertainty, and the model design will account for this. One approach is to use an **ensemble of models**: for example, use projections from multiple climate models as inputs, run the tourism impact prediction for each, and then present a range or distribution of outcomes (rather than a single number). The AI could also assign confidence intervals to its predictions (using techniques like quantile regression or Monte Carlo simulation where input variables are varied within plausible bounds). This information will be conveyed to users (e.g. showing best-case, worst-case scores) to inform risk management decisions.
* **Integration of Expert Rules:** Beyond the learned model, the AI design can integrate some rule-based intelligence derived from experts. For instance, if Delphi experts assert a rule like “if a destination has more than 50% of GDP from tourism and is projected to lose >20% of tourist arrivals, it should be flagged as highest risk regardless of other factors,” the system can include such logic as an override or as part of the scoring calculation. This hybrid AI approach (combining data-driven learning with expert system rules) ensures that domain knowledge that might be hard to learn from data (especially unprecedented changes) is embedded.
* **Continuous Learning and Updates:** The model design will consider the ability to update as new data comes in. For example, as the years go by, actual tourism numbers under evolving climate conditions can be fed back to re-train or fine-tune the model (this could even be semi-automated if the tool is maintained after the PhD). The architecture might allow swapping in a new model file or adjusting parameters without rebuilding the whole system. In essence, CRISI’s AI component is not one static model but a **framework for ongoing learning** – starting with the PhD’s trained model and improving over time as more information becomes available or as the situation changes (like unexpected shifts in travel due to factors like pandemics, which might also be considered).

Overall, the AI model design for CRISI is meant to be **robust, interpretable, and aligned with expert knowledge**. By combining statistical learning with expert-informed structure, the model will provide credible insights for policymakers and investors, rather than just numbers from a black box. This design philosophy enhances trust in the tool’s outputs, a crucial factor for adoption in policy and investment circles.

**Data Sourcing and Preprocessing**

Building CRISI requires assembling a diverse array of data and carefully preprocessing it for use. Below we outline the data sources and processing steps, emphasizing how spatial and economic data under climate scenarios will be handled:

* **Climate Data Sources:** We will utilize high-quality climate projections for Europe, likely from the **Copernicus Climate Change Service (C3S)** and other research institutions. This includes:
  + **Temperature and Precipitation Projections:** Downscaled model outputs (e.g. EURO-CORDEX) providing future monthly or seasonal averages, extremes (like days above 35°C, or heavy rainfall events). These will help identify heat stress periods, drought frequency, etc. per region.
  + **Snow and Snowpack Data:** Crucial for winter tourism, projections of snow cover days or snow depth will be gathered (some C3S sectoral datasets focus on snow indicators for tourism).
  + **Sea Level Rise and Coastal Flood Risk:** For coastal destinations, data on projected sea-level rise and flood return periods (perhaps from EU Joint Research Centre or IPCC reports) will be included to gauge long-term viability of coastal infrastructure.
  + **Other Hazard Indicators:** Wildfire risk maps, water scarcity indices, or storm intensity projections for Europe, as relevant to tourism (like increased wildfire risk in Mediterranean forests affecting nature tourism, or storm surge affecting cruise ports).
  + These datasets often come in grid format (rasters). Preprocessing will involve **spatial aggregation**: overlaying the climate data with tourism regions (NUTS2/NUTS3 or other chosen spatial units) to compute regional averages or frequencies. For example, if using NUTS3 regions, for each region we’ll calculate the average summer temperature increase or the number of hot days per year from the climate model grid cells overlapping that region. This yields a table of climate indicators by region and scenario. We will ensure to cover at least two time horizons (mid-century and end-century) and two scenario severities, to capture a range.
* **Tourism and Economic Data Sources:** To gauge the economic side:
  + **Tourism Statistics:** Eurostat provides data such as nights spent at tourist accommodations by region, seasonal occupancy rates, tourism employment, etc. We will collect historical data (e.g. the last 20 years) to detect trends and feed the model. Additionally, country-level data from the World Tourism Organization (UNWTO) or World Travel & Tourism Council (WTTC) can offer insight on tourism’s GDP contribution, visitor exports, etc., which might be downscaled or used as benchmarks.
  + **GDP and Demographics:** Regional GDP, population, income levels from Eurostat will contextualize how significant tourism is in each region’s economy (tourism GDP share). Also, development indicators like education or infrastructure quality might serve as proxies for adaptive capacity.
  + **Existing Resilience Measures:** If available, data on adaptation efforts (e.g. number of climate adaptation projects funded in a region, or existence of a climate adaptation plan for the tourism sector) would be valuable. These might come from reports or databases of EU-funded projects (e.g. Interreg programs on sustainable tourism, Climate-ADAPT case study database). Even if qualitative, such info can be coded (like a binary indicator if a region has a plan or not).
  + **Geospatial Boundaries and Maps:** Shapefiles for European regions for mapping purposes, and possibly land-use/land-cover data if needed to understand environment context.
* **Preprocessing Steps:** Once data is collected:
  + **Cleaning and Quality Control:** Fill or interpolate any missing values in time-series (for tourism stats, there might be gaps or anomalies – e.g. the 2020 pandemic year is an outlier that may be handled carefully or excluded in certain analyses). Ensure consistency of units and currency (adjust revenues for inflation, etc.).
  + **Normalization and Scaling:** For modeling, numeric variables might be standardized. But for the scoring output, we might need to normalize indicators to a common scale (e.g. 0 to 1) before weighted aggregation. We will define baselines – e.g., the historical period average climate could be baseline 0, and deviations in 2050 are measured relative to that.
  + **Spatial Joins and Index Calculations:** Use GIS operations to attach climate data to regions. Compute indices like the Tourism Climate Index (TCI) for each region and year in the historical period (TCI is based on temperature, humidity, etc.; we can calculate it from meteorological data). Similarly, for future scenarios, compute projected TCI. This provides a time series (historical) and scenario trajectories (future) of a key climate suitability metric for tourism[visitzagrebcounty.hr](https://visitzagrebcounty.hr/en/odrzivi-turizam-u-zagrebackoj-zupaniji-izazovi-i-prilike-u-doba-klimatskih-promjena/#:~:text=Interreg%20Euro). Do analogous computations for other indices (like ski tourism days, beach comfort index, etc.).
  + **Scenario Data Formatting:** We will organize scenario data in a structure like: each region has multiple records (one for each scenario & time), containing all indicator values and the resulting score. This will feed the tool – essentially a table that the tool can query quickly instead of running raw calculations every time. Heavy climate data processing will mostly be done offline in the research phase, producing these summary tables to optimize the tool’s performance.
  + **Validation of Data:** Cross-check that the derived indicators make sense. For example, if the data suggests a particular region’s tourist numbers correlate strongly with an indicator, verify qualitatively (with literature or local knowledge) that the relationship is logical. Also ensure no significant data biases (like much more data available for some countries than others – which could bias a model).
* **Data Example:** To illustrate, suppose for a region in Southern Spain, we gather that currently it experiences on average 20 very hot days (>35°C) each summer, and by 2050 under RCP8.5 it’s projected to have 60 such days. We also find the region’s tourism GDP is 15% of total GDP and it has experienced declines in summer visitors during past heatwaves. We encode these: an indicator for heat days jumping from 20 to 60 (a 200% increase), and note high economic sensitivity. The preprocessing pipeline would flag this region as one likely to see stress, even before formal modeling – and this data flows into the model which quantifies how a 200% increase in hot days translates to change in tourism demand (based on historical elasticities). This ensures our tool is grounded in actual measured data and scientifically modeled projections, not guesswork.
* **Data Management and Documentation:** All data sources will be documented (source URLs or references, date accessed, etc.) and stored in a version-controlled repository if possible. This is important for transparency and for future updates (so that new data can be appended in the same format). The preprocessing scripts (in Python or R) will be saved as part of the project to allow re-running if data is updated. This disciplined approach to data handling is part of ensuring the **methodological rigor** of the project – anyone reviewing the PhD or using the tool can trace where the numbers are coming from and how they were processed.

In summary, **reliable data and careful preprocessing** form the backbone of CRISI. By using authoritative sources and preparing the data thoughtfully (including deriving meaningful indicators), we lay a solid foundation for the model to produce credible and insightful results about climate resilience in tourism.

**User Interface Design**

The user interface (UI) is what will make CRISI accessible and useful to policymakers and investors. The design will focus on clarity, interactivity, and delivering actionable insights. Key considerations and features of the UI include:

* **Target Users and Use Cases:** We anticipate users such as national tourism planners, regional development agencies, investment fund managers focusing on infrastructure or hotels, and researchers/consultants in climate adaptation. Thus, the UI should cater to both technical and non-technical audiences. A policymaker might use it to identify which regions need more support or to justify funding allocations for adaptation. An investor might use it to assess risk when considering a project in a particular location. These use cases drive the interface design towards simplicity in presenting the **resilience scores and underlying factors**.
* **Dashboard Layout:** The main screen will likely be a **dashboard** with a European map and summary metrics. Key components:
  + A **map view** showing the resilience score by region (color-coded). Users can pan/zoom and click on regions. The map could have layers to toggle: e.g., one layer for overall resilience score, others for individual dimensions (exposure, sensitivity, etc.) if the user wants to explore what drives the score.
  + A **sidebar or popup** that appears when a region is selected, showing detailed info: the region’s score, a breakdown of contributing factors (maybe a bar chart showing scores for sub-indices like “Climate Exposure = X, Adaptive Capacity = Y”), and key data points (e.g. projected tourism demand change +/-, current tourism GDP, population, any notable adaptation measures listed). This contextual information helps users understand *why* a region got its score – important for trust in the tool.
  + **Filters and controls** at the top: dropdowns or sliders to select the scenario (e.g. scenario A vs B), time horizon (2030 vs 2050 vs 2100), and perhaps the type of tourism or season of interest (if the model differentiates between summer beach tourism vs winter ski tourism, for instance). By adjusting these controls, the map and data update, allowing users to compare different futures or assumptions.
  + Possibly a **ranking table** view: some users might prefer to see a list of regions sorted by risk, highest to lowest, to quickly identify hotspots. We can include a toggle to switch the view to a sortable table of scores (with search function to find a specific region).
* **Visual Design and Clarity:** We will use intuitive color schemes (e.g. green = more resilient, red = high risk) with a legend explaining the scale. Tooltips and info icons will provide definitions (e.g. what does a “resilience score” exactly mean, how it’s calculated in simple terms) so users aren’t confused by technical jargon. Each chart or figure will have clear labels. We will avoid clutter – only essential information is shown by default, with the option to drill down for those who want more details. Short textual explanations might accompany findings (e.g. “Region X is rated high risk due to significant projected climate impacts and high economic dependence on tourism”). These could even be auto-generated summaries based on the data, to guide users in interpreting results.
* **Expert Input & Scenario Exploration:** An advanced feature (possibly beyond the minimum viable product) is to let users simulate *what-if scenarios*. For example, a policymaker could adjust a hypothetical “adaptive capacity” slider to see how much improving certain conditions (like investing in infrastructure, or diversifying tourism offerings) would improve the score. This kind of interactive scenario testing can make the tool a **planning aid**, not just an assessment. Initially, the UI will incorporate scenario choices for climate conditions (which are data-driven). Later, if the model allows, adding user-driven scenarios (like “assume adaptation investment increases capacity by X%”) could be included. The design will ensure it’s clear which outputs are based on default model data versus user-modified assumptions.
* **Responsiveness and Accessibility:** The UI will be web-based and designed to be responsive (viewable on large monitors in offices as well as tablets in meetings). It will follow accessibility best practices – e.g. color choices that are colorblind-friendly, ability to enlarge text, etc., since policy users may have specific requirements. Also, multi-language support might be considered if targeting various European countries (at least ensuring it’s easily localizable by external contributors, given the context).
* **User Guidance and Documentation:** Recognizing that not all users are climate experts, the interface will provide guidance. For example, a **help section or tutorial** explaining how to use the tool, and a glossary for terms like RCP scenarios, exposure vs. sensitivity, etc. There might also be a “methodology” button that gives a high-level summary of how the score is computed (with a link to the academic documentation for those who want the full detail). This builds trust and helps users properly interpret the outputs – avoiding misuse or misinterpretation.
* **Visualization Examples:** If describing in the dissertation or documentation, we’ll include sample screenshots or mock-ups. For instance, a map showing, say, 2050 outcomes where parts of Southern Europe are colored red (low resilience) and Northern regions green, with a popup for a region like Andalusia stating it faces a projected 25% drop in summer tourism under scenario X, giving it a low resilience score. The UI would highlight that and possibly suggest “key vulnerabilities: heatwaves, water scarcity; key strengths: high adaptive capacity in cities” based on data. Another example could be a time-series chart: when selecting a region, a chart could show tourism demand projections over time for different scenarios (illustrating how outcomes diverge if climate change accelerates). Such visualizations make the abstract concept of future risk more concrete and help in communication with stakeholders.
* **Iterative Design with Feedback:** Given the PhD timeframe, the UI will likely go through prototype testing with a few end-users (maybe via informal sessions or as part of expert validation). Their feedback on usability and clarity will be incorporated. The design is expected to evolve from a basic functional interface to a more polished dashboard by the end of the project. Post-PhD, professional UI/UX designers could further refine it for widespread deployment, but the initial design will aim to be fully functional and user-friendly, demonstrating the concept effectively.

In essence, the CRISI UI aims to transform complex data and model results into a **practical decision-support tool**. By focusing on user needs, interactive exploration, and clear presentation, the tool can bridge the gap between scientific analysis and real-world policy and investment action.

**Deployment and Scalability**

A clear plan for deploying the CRISI tool and scaling it beyond the prototype phase is crucial to ensure it has real impact. Here we outline the deployment approach and how the system can be expanded or scaled:

* **Prototype Deployment (PhD Phase):** During the PhD, the tool will likely be deployed in a **limited environment** for demonstration – e.g. running on a local server or university server for controlled access. This is sufficient for development, testing, and showing case studies. However, the architecture will be built with eventual cloud deployment in mind. Containerization (using Docker or similar) will be employed so that the entire application stack (data, backend, frontend) can be packaged and run consistently on any server. By the end of the PhD, the goal is to have a working prototype accessible via the web (even if just in a pilot capacity), demonstrating core features.
* **Full Deployment (Operational Tool):** For wider use, hosting on a **cloud platform** (such as AWS, Azure, or a European cloud service to meet any data sovereignty requirements) is planned. The application would be set up with:
  + **Scalable Server Infrastructure:** Using cloud services that can scale resources based on demand. For example, the processing layer API might run on a cloud function or auto-scaling cluster, so if many users query at once or heavy computations are triggered, it can handle the load.
  + **Database Hosting:** A managed database service for the data layer (ensuring backups, reliability). Given the mostly read-heavy workload (users querying data rather than continuously writing), a replication strategy can be used (read replicas to handle multiple simultaneous requests).
  + **Content Delivery and Load Times:** The static assets of the UI (HTML/JS, map tiles, etc.) can be served via a content delivery network (CDN) to ensure fast load globally. Also, since some computations might be heavy (e.g. processing new scenario data), those will be done offline and the results cached – the deployed tool mostly serves precomputed results or runs lightweight calculations on the fly, making it responsive.
* **Maintenance and Updates:** The design includes pathways for **regular updates**:
  + Climate data can be updated when new scenarios or improved models are released (e.g. incorporating CMIP7 data in the future). Because the system is data-driven, updating data shouldn’t require recoding the tool – just preprocessing new inputs and updating the database. Ensuring the data ingestion process is automated (scripts and documentation) will facilitate this.
  + Tourism/economic data can be updated annually or as new stats come (the system could be linked to APIs if available, or manual data update workflows).
  + The AI model can be retrained with new data periodically. If a major model update occurs, a versioning system will be in place so that we can deploy the new model while possibly retaining an older model for comparison. The API could even allow switching between model versions if needed.
  + Bug fixes and feature enhancements: using best practices like version control (git) and continuous integration will make it easier to manage code changes. After the PhD, if the tool is taken up by an organization, a dedicated dev team might maintain it; hence writing clear code and documentation during development is important for handover.
* **Scaling to Other Contexts:** Although initially focused on Europe’s tourism sector, the framework is intentionally generalizable. Scalability considerations include:
  + **Geographic Scaling:** The system could ingest data for other regions of the world, or downscale to more local levels within Europe. We ensure that no component is hard-coded to Europe (e.g. region identifiers could be flexible). The biggest task in scaling geography is obtaining analogous data; the system’s modular design can accommodate that if data is available.
  + **Sectoral Scaling:** The underlying approach (climate resilience scoring using AI + expert input) could be applied to other sectors beyond tourism (like agriculture, energy, etc.). While the PhD won’t do this, the software could be a template. By abstracting the code (for example, not hardwiring tourism-specific assumptions in deeper layers), it would be feasible to adapt CRISI for other sectors. A future direction might be to create a suite of “Climate Resilience Investment Scoring” tools for different sectors, sharing a platform.
  + **User Scaling:** If the tool becomes widely used, we’ll implement proper user management, access control, and possibly cloud cost optimizations (since running what-if simulations for many users could be computationally expensive). This includes perhaps a freemium model or restricted heavy computations to certain authorized users if needed. However, given likely use by public agencies, an open-access model is desirable – thus we plan for efficient use of resources to keep it sustainable cost-wise.
* **Performance and Optimization:** To ensure the tool remains fast as it scales, optimization steps will be taken. Heavy computations can be pre-run (e.g. computing all region scores for each scenario-year combination and storing them, so the tool mostly just retrieves and displays). Lazy-loading of data in the UI (loading detailed data only when needed) will keep initial loads quick. Scalability tests (simulate multiple concurrent users) will be done to identify bottlenecks. If certain analyses are slow, we might implement asynchronous processing (so a user could request a complex analysis and be notified when it’s done, rather than blocking the interface).
* **Reliability and Backup:** For an operational tool, having uptime and backup plans is important. We’ll incorporate error handling (so that if a data source is temporarily down, the tool fails gracefully with a message rather than crashing). Regular backups of the database will be scheduled. If deploying in the cloud, we might use multiple zones or regions to ensure resilience against server outages. Essentially, applying standard IT best practices for a production system.
* **Security and Privacy:** Although the data here is mostly public or non-sensitive, we will enforce security measures – secure endpoints, encryption (HTTPS), and ensure compliance with any relevant regulations (for instance, if any user data or login is involved, comply with GDPR). Since this is a climate policy tool, data privacy is not a big concern, but cybersecurity (avoiding disruptions or tampering) is; thus, secure coding and possibly third-party security audits would be considered if it becomes mission-critical for users.
* **Scalability Path Example:** After the PhD, suppose the European Commission or an international organization is interested in CRISI. We could transition the tool to their infrastructure, feeding in official data regularly. The path might be: PhD prototype -> pilot with a partner agency (testing with real decisions, say in a particular country) -> secure funding to operationalize -> full deployment on agency’s platform. Each step requires scaling up the robustness of the system, which this plan anticipates. By building a cloud-ready, modular tool from the start, we make this transition feasible.

In summary, the deployment plan ensures that **CRISI can grow from a research prototype into a live policy tool**. The use of modern, scalable technologies, combined with good software practices, means the tool can handle increasing data volumes, more users, and broader scope without fundamental redesign. This aligns with the vision of the PhD work being not just an academic exercise but the seed of a practical solution for climate resilience planning in tourism.

**Validation Strategy and Case Studies**

Validation is a critical component of both the PhD research and the development of the CRISI tool. We will implement a multi-pronged validation strategy to ensure the methodology is sound and the tool’s outputs are reliable and credible. This includes quantitative validation (testing the model against data) and qualitative validation (expert and case-study feedback):

* **Quantitative Model Validation (Cross-Validation & Back-Testing):** During model development, standard statistical validation techniques will be applied. For instance, using k-fold cross-validation on the historical dataset to check how well the model predicts unseen data. Performance metrics like Mean Absolute Error for tourism demand predictions will be reported. If the model is used to predict past known events (e.g. a particularly hot summer and its impact on tourism), we will compare the model’s prediction to actual observed declines in tourist numbers. A good agreement increases confidence in the model. If discrepancies are found, we analyze why – perhaps identifying missing variables or nonlinear effects – and adjust the model accordingly. This iterative refinement continues until the model captures key patterns reasonably well. Additionally, **sensitivity analysis** will be conducted: for example, varying an input by ±10% to see how the score responds. This helps ensure the model’s behavior is logical (monotonic where expected, etc.) and that no single factor is unduly dominating unless justified.
* **Case Study Validation:** We will apply CRISI to specific real-world case studies as both demonstration and validation:
  + *Selection of Case Studies:* These will be chosen to represent diverse contexts (e.g. a ski resort town in the Alps, a Mediterranean beach destination, a northern European city focusing on cultural tourism). This tests the tool across different sub-sectors of tourism and climate challenges.
  + *Procedure:* For each case, we gather localized data (even more detailed if possible than the general dataset) and run the CRISI assessment. We then compare the results with known historical impacts or existing assessments. For instance, if a region has already been identified in literature or by local authorities as highly vulnerable, does CRISI also rate it as high risk? If a city has implemented adaptation measures and claims improved resilience, does the tool reflect a better score for it relative to similar cities without such measures?
  + *Validation with Local Data:* If available, we might use local impact studies or surveys (like tourist perception surveys of climate or economic reports) to validate our outputs. For example, a local survey might indicate tourists already find summers too hot; if CRISI’s projection shows a significant drop in demand due to heat by 2050, that aligns qualitatively. Conversely, if CRISI projects no issue but locals are already concerned, that flags a potential model gap (perhaps a microclimate or specific draw isn’t captured in our broader data).
  + Each case study chapter (Chapter 7 in the dissertation) will discuss these comparisons. Generally, we expect CRISI to capture broad strokes correctly (based on robust global/regional data), but fine-tuning may arise from these specific insights. The tool’s parameters can be adjusted if, say, we systematically under-predict risk for a certain type of destination encountered in case studies.
* **Expert Review and Feedback:** After building the model and running case studies, we will conduct an **expert review session** – this can be considered a validation-oriented extension of the Delphi process. In practice, this might be a workshop or individual interviews where we show experts the CRISI results (for case studies or even a full map of Europe under scenario X) and solicit their evaluation:
  + Experts will be asked: *Do these results align with your expectations and experience?* For instance, if CRISI flags Country A’s coastal areas as extremely high risk by 2050, does that resonate with what experts know about those areas? If an expert disagrees, we dive into why – maybe the expert knows of a new adaptation project not accounted for, or they suspect our climate data for that region is too pessimistic.
  + We will also present the methodology and have experts critique it. This serves as a peer-review of sorts for the PhD work’s validity. If an aspect is unconvincing to experts, that’s a cue to strengthen that part (either by better explaining it, adding missing data, or adjusting the method).
  + If possible, incorporating a few **policy-makers or end-users** in this review is valuable. Their perspective on whether the outputs are understandable and useful is a form of validation of the tool’s design. They might, for instance, try a sample decision: “Given these results, would you allocate funds differently? Does it provide new insight or just confirm what you already knew?” Positive feedback here indicates the tool has practical validity (not just technical).
* **Comparative Validation:** We may compare CRISI’s outputs with other indices or frameworks as a consistency check. For example, see if countries that rank highly on generic climate vulnerability indices (like Germanwatch’s Climate Risk Index or ND-GAIN Country Index) also appear as high-risk in our tourism-specific index – they won’t match perfectly (because CRISI is sector-specific), but broad alignment in extremes would be reassuring. We can also compare our tourism demand projections with those from other models (like the JRC’s projections[adaptecca.es](https://adaptecca.es/sites/default/files/documentos/2023-jrc-regional-impact-cc-european_tourism-demand.pdf#:~:text=demand%2C%20with%20coastal%20regions%20being,reductions%20in%20tourism%20demand%3B%20that) or OECD studies) to ensure we’re in a reasonable range. Significant deviations would prompt investigation.
* **Validation of Software Tool (Usability Testing):** Beyond the model, the software itself needs validation in terms of usability and correctness:
  + We’ll perform **functional testing** on the tool – checking that for known inputs we get the expected outputs (e.g. if we input scenario = present day, do we get scores reflecting current known situation; or testing edge cases like a region with zero tourism gets appropriate handling).
  + **User testing** with a small group can validate that the interface is intuitive. If testers consistently misinterpret something, we refine the UI. This overlaps with the UI design feedback process.
  + Performance validation: testing the speed and reliability (does the map load quickly, are calculations done within a few seconds). If not, optimize accordingly.
* **Iterative Improvement:** The validation process is not a one-time at the end; it’s iterative. Early on, as soon as a partial model or prototype is ready, some validation steps (like cross-validation and basic expert opinion checks) will occur, so that issues can be caught and resolved early. By the project’s end, the validation chapter will report on all the tests done and modifications made in response. The outcome should be a **high confidence in the tool’s accuracy and usefulness**.
* **Final Demonstration:** As a culmination, the validated tool might be demonstrated on a real policy question as a form of validation. For example: *“Where should climate adaptation funds for tourism be prioritized in the next EU budget?”* Using CRISI, we produce a ranked list of say 10 high-risk areas. If this aligns with independent risk assessments or expert consensus, it’s a strong validation of the tool’s policy relevance. If it yields some surprises, those could either be new insights (a success of the tool) or indicate where further validation is needed. Either way, it provides a concrete test of the tool’s practical value.

By employing these rigorous validation steps – from data and model verification to expert and user feedback – we aim to ensure that CRISI is not just theoretically sound but also **trusted by stakeholders**. This thorough validation will be documented in the PhD, giving readers and future users confidence that the tool has been critically evaluated from all angles.

**Feasibility, Timeline, and Future Outlook**

The proposed plan for developing CRISI is ambitious but structured to be **realistic within a PhD timeframe**, typically 3–4 years, while setting the stage for future expansion into an operational tool. Here we outline a rough timeline and how scope is managed, as well as the post-PhD outlook:

* **Year 1 – Foundations:** Focus on literature review and conceptual framework. In this phase, the student will immerse in the interdisciplinary literature, identify data sources, and refine research questions. By the end of Year 1, we expect a clear chapter outline (as above), a preliminary conceptual model of CRISI, and possibly initial data gathering. This sets the academic foundation and ensures the methodology is well-grounded. (Also, any necessary training in climate data handling or machine learning techniques would occur here.)
* **Year 2 – Data & Prototype Model:** Concentrate on data collection and preliminary modeling. The heavy lifting of assembling and preprocessing the data happens in early Year 2. Simultaneously, an initial model (perhaps a simplified version) is developed to test feasibility. By mid-Year 2, enough progress is made to initiate the Delphi process – the first expert consultation can occur once we have a draft list of indicators and perhaps some early results to show. Incorporating Delphi feedback, the model is revised. By the end of Year 2, the aim is to have a working prototype of the scoring model and possibly a basic prototype of the tool (even if not full-featured, something that can generate results for selected regions). This is also when a transfer from pure research to applied development begins – perhaps engaging any collaborators for tool programming.
* **Year 3 – Tool Development and Case Studies:** This year sees the parallel tasks of building out the software tool (front-end, back-end, etc.) and applying the model to case studies for validation. The PhD student might collaborate with a software engineer or use available libraries to accelerate development of the UI and architecture described. By mid-Year 3, the case studies are conducted; their feedback loops into final adjustments of both model and tool interface. The expert review workshop would likely happen around this time as well, once there’s a tangible tool to demonstrate. This year is intensive in integration – ensuring the academic work (model, analysis) and the practical tool (software) come together. Writing of dissertation chapters (Methodology, Results, etc.) will proceed concurrently, based on these outcomes.
* **Year 4 – Finalization and Testing:** If the PhD program has a fourth year, it will be devoted to writing the dissertation, addressing any remaining gaps, and polishing the tool for demonstration. Final validation steps and perhaps publishing parts of the work in journals occur here, which also serve to validate and get peer feedback. By the defense, the student should have both a substantial dissertation and a functional CRISI prototype to showcase. This prototype might cover, say, an interactive map for Europe with at least one scenario fully implemented. The scope is kept manageable by possibly limiting some features (for instance, maybe not all climate scenarios or not a fully public deployment yet), but the core functionality is there.

**Policy and Investor Relevance during PhD:** Throughout the project, we plan ongoing engagement with stakeholders (even beyond formal Delphi rounds). This could be through presenting at conferences, policy workshops, or investor meetings to gather input and generate interest. This not only ensures the research stays aligned with user needs, but also paves the way for the tool’s adoption after the PhD.

**Expandability Post-PhD:** After the PhD, the vision is to **expand CRISI into an operational tool**. The dissertation itself (especially Chapter 8 discussion) will outline specific next steps, such as:

* Broadening data coverage (e.g. adding more granular local data or economic factors if they were initially omitted due to time constraints).
* Hardening the software (turning the prototype into a production-ready application with the full deployment strategy described).
* Possibly pilot projects in collaboration with an EU body or a national government to implement CRISI in their workflow, which would provide real-world testing at scale.
* Seeking funding or partnerships for maintenance – for example, the tool could be hosted on Climate-ADAPT or a similar platform so it has institutional support. Since CRISI aligns with EU climate adaptation and regional development goals, there could be interest in integrating it with those knowledge portals.

**Methodological Rigor Maintenance:** Even as it expands, the tool’s credibility will rely on maintaining methodological rigor. Therefore, the plan includes writing detailed documentation and even publishing the underlying model in academic journals. This way, future users or developers have a clear understanding of the assumptions and can update the methodology as science progresses (e.g. if new research suggests a better way to measure “tourism adaptive capacity,” the tool could incorporate that).

**Conclusion:** In conclusion, this detailed structure and methodology for CRISI brings together a strong academic framework (suitable for a PhD dissertation) and a practical blueprint for tool development. By balancing ambition with realistic milestones, the plan ensures that by the end of the PhD, we have both a well-validated **“Climate Resilience Investment Scoring” model for tourism** and a functional prototype tool demonstrating its value. This work will yield immediate insights for policy (through case studies and expert engagement) and create a launchpad for a fully operational system that can guide climate-resilient investments in Europe’s tourism sector for years to come. The integration of spatial climate-economic data, AI modeling, and expert knowledge makes CRISI a novel and impactful contribution, addressing identified gaps in how we plan for climate change in the tourism industryumu.diva-portal.org and providing a much-needed bridge between climate science and investment decision-making in the European context.