Development of an Impact Model for Climate Adaptation Strategy Design: The Case Study of Basilicata Region, Italy

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Abstract. As climate adaptation gains prominence in policy and planning, the development of operational tools to support strategy formulation becomes increasingly critical. This paper presents an integrated impact model developed within the framework of the GD-CURE (GeoDesign for Climate Urban Neutrality) project, aimed at enhancing territorial governance in climate adaptation and mitigation planning. The model adopts a flexible, scalable structure to support informed decision-making across multiple territorial levels. It had been adopted in a stakeholder co-design strategic workshop to evaluate and compare alternative scenarios, balancing environmental benefits with resource constraints. Applied to the Basilicata Region in Italy, the tool assesses potential impacts of selected adaptation and mitigation measures in real-time using a spreadsheet-based platform. Results demonstrate the model's capacity to simulate GHG reduction outcomes and spatial intervention coverage, facilitating prioritization in a short, participatory Geodesign workshop. Future research will extend the tool's application to additional case studies, refining its operational capabilities and transferability. The findings underscore the importance of integrating scientific evidence, stakeholder input, and policy frameworks to meet ambitious climate goals effectively.

Keywords: Climate Change · Climate Adaptation Planning · Adaptation · Nature Based Solutions · Stakeholder Participation · Geodesign

1 Introduction

Supporting tools for climate adaptation strategy design are growing following local implementations and case studies. A critical stage in climate mitigation accounting is the measurement of specific impacts connected with territorial strategies integrating multiple local actions and/or investments. This issue is part of a wider research titled GeoDesign for Climate Urban Neutrality (GD-CURE) aiming to develop tools and methods supporting territorial governance in climate planning [1–3]. Through a multi-scale approach integrating local, national, and macro-regional perspectives, GD-CURE facilitates sustainable urban and territorial development.

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The objective of this paper is to develop an integrated impact model to support the formulation of climate adaptation strategies [4]. The model is designed as a flexible and scalable tool, applicable across different territorial scales and contexts. Its purpose is to facilitate informed decision-making that aligns with criteria for resource optimization and the maximization of environmental benefits. The tool is applied as a case study to the Basilicata Region, Italy.

Within the broader framework of European and national climate adaptation policies, the European Union has significantly reinforced its commitment. This commitment is exemplified through key frameworks such as the Paris Agreement and the European Green Deal [5], which set ambitious targets requiring proactive engagement from public authorities at all levels of governance [6].

In Italy, the National Climate Change Adaptation Strategy (SNAC), established in 2015, represents the cornerstone of national efforts to address climate adaptation challenges. SNAC serves as a comprehensive guide for integrating adaptation measures into national, regional, and local planning processes. Organized around four core objectives—reducing vulnerability across natural, social, and economic systems, enhancing adaptive capacity, leveraging emerging opportunities, and promoting coordinated action—the strategy forms a robust framework [7].

Complementing SNAC, the National Adaptation Plan to Climate Change (PNACC) provides a methodological framework for regional governments. PNACC guides the development of localized strategies, emphasizing participatory processes, climate risk assessment, and priority action identification. This approach underscores the role of regional administrations in establishing adaptive governance models supported by scientific evidence and stakeholder involvement. Notably, the Basilicata Region employs Geodesign methodology to address environmental vulnerabilities such as landslides, floods, heatwaves, and rural depopulation, steering planning practices towards integrated and sustainable governance [8].

Despite regional efforts, Italy faces challenges due to the absence of a unified national adaptation framework. This has led to fragmented strategies embedded within broader sustainability agendas, hindering interregional collaboration and coordinated responses to cross-boundary climate risks. Lombardy and Emilia-Romagna have pioneered regional strategies, with other regions like Sardinia, Aosta Valley, and Piedmont following suit. However, disparities in strategy development persist, with some regions like Puglia and Trento still progressing.

Following the research strategy defined by the "GeoDesign for Climate URban nEutrality (GD-CURE)" project this impact model tool supported the participation of various actors in the development of local strategies and plans for climate change adaptation and mitigation [9–11]. The design of the integrated impact model responds to a key question: How can stakeholder participation be effectively organized and structured to support informed decision-making that balances the dual objectives of optimizing limited financial resources and maximizing benefits in terms of adaptation and mitigation?

Accordingly, the proposed tool is designed to support the iterative and interactive development of alternative implementation scenarios for adaptation and mitigation measures. It enables stakeholders to explore and define different prioritization strategies and resource allocation approaches, while providing a framework to visualize and compare

the resulting impacts, both in terms of mitigation effectiveness and the extent of territorial components affected by each option. The application of the tool is based on the preliminary selection of a list of actions, combining mitigation and adaptation objectives. These options are aligned with the thematic domains defined by the International Geodesign Collaboration (IGC) Global Climate Geodesign Challenge (GC). The domains considered include: Energy, Agriculture, Forest, Ocean, Settlement, Industry, Transportation and Water.

2 Interactive Tool for Scenario Development and Evaluation

Among the tools developed through the GD-CURE research, the impact model assessment stands out as a key component for demonstrating the projected outcomes of climate mitigation planning [12]. It functions both as a scenario-building and benchmarking tool, as well as a dashboard to support negotiation and consensus-building within participatory processes for co-designing Climate Mitigation Strategies. To ensure real-time usability, a simplified approach was adopted to estimate the mitigation and adaptation effects of each action. This approach relies on generalized performance and cost parameters associated with specific action characteristics. While this represents a significant simplification, it is necessary at this stage, as the detailed appraisal required for local implementation—dependent on specific project dimensions—remains beyond the current scope of strategic planning.

Given these considerations, the tool offers effective support for real-time scenario development and is therefore highly applicable within the context of Geodesign workshops.

The tool is designed to allow as input the share of investment per domain and per actions. Grounding this financial driven decision model on an accurate simulation of potential public investments programs connected with the implementation of the Climate Adaptation Strategy at regional scale, the tool provides stakeholders and decision makers with a dashboard to simulate the adaptation/mitigation effects related to investments on specific actions defined also in the spatial perspective for the case study region. For example, within the urban domain, increasing the budget allocation for the action "Urban green infrastructure planning and nature-based solutions" from 10% (€10 million) to 15% (€15.1 million) leads to an expansion of the targeted urban area from 12.62 ha to 18.93 ha. This adjustment also results in a rise in mitigation benefits, from 104.62 to 156.93 tons of carbon dioxide equivalent per hectare per year.

The interactive impact model is grounded in the analytical framework developed within the GD-CURE research project, which identifies eight domains and 58 specific actions. These domains—Energy, Agriculture, Forest, Ocean, Settlement, Industry, Transportation, and Water—are derived from the International Geodesign Collaboration (IGC) and the Global Climate Geodesign Challenge (GC). Actions are selected based on their relevance, feasibility, and suitability to address climate challenges in the specific case study area.

The tool encompasses a total of 58 actions, distributed as follows: 8 actions pertain to the agricultural sector, 2 to forestry, 14 to industry, 6 to transportation, 8 to water management, 4 to marine environments, 8 to urban settlements, and 8 to energy systems.

Supporting this model is a knowledge-based Handbook [13], designed to facilitate the identification and spatial deployment of mitigation and adaptation measures across the aforementioned sectors. This tool is particularly valuable for policymakers, planners, and other stakeholders engaged in strategic climate action, as it enables a comparative assessment of intervention options aligned with specific regional and local priorities. Furthermore, the classification of actions into broader categories enhances cross-sectoral coherence and supports integrated climate resilience strategies [14].

The interactive impact model allows to distinguish between different costs categories related to each action. In facts, "Cost indicators" refer to metrics relevant to estimating the demand of financial resources required for implementing/ managing an option and include implementation costs, maintenance costs, loss of profits and marginal abatement costs.

Another relevant feature to base the impact model are the "Incidence indicators". Those refer to metrics used to evaluate the quantity of domains components targeted by a specific action, given a cost factor and budget constraints. The following figure describes the interactive impact model structure.

The interactive tool is articulated on four components: i) Budget, defining the available financial resources relevant to the IGC domains; ii) Parameters, presenting, for each domain, information on the actions, cost per unit of the considered domain component and mitigation outcomes per unit of the considered domain component; iii) Domain User Interface, enabling the construction of alternative scenarios by distributing the budget of each domain among the actions and monitoring the resulting mitigation outcomes; and iv) Results, presenting the cumulated expenditure, mitigation outcomes and relative incidence of individual domains, resulting from the implementation of the actions in the time period 2022–2050.

Budget:

The Budget section outlines the budget constraints that guide the allocation of funds to the IGC domains. The Section is articulated on four sub-sections; Sect. 1 presents the programs and funds relevant to financing the proposed adaptation/ mitigation options, the amount of available financial resources deriving from the selected funds and the total budget destined to funding the implementation of the proposed options. A chart visualizes the ratio of individual funds to the total budget. The selected funds derive from programs activated for the 2021–2028 programming cycle. The time interval considered, from 2022 to 2050, is divided into four cycles. The scenario development process assumes that equal budgets are available for each cycle and that the budget distribution among the domains remains constant across the four cycles. The relevant programs are Regional Operating Programs (RP) including the European Regional Development Fund (ERDF) and European Social Fund plus (ESF +) and Rural fund (RDC) including the European Agricultural Guarantee Fund (EAGF), the European Agricultural Rural Development Fund (EARDF) and National and Regional Funds.

The available budget amounts to 982.6 M€ for the RP - including 774.5 M€ from ERDF and 208.1 M€ from ESF + - and to 450.4 M€ for the RDC, including 227.5 M€ from EAFRD and EAGF and 222.9 M€ from National and Regional funds. Sub-Sects. 2 and 3 outline the priorities of the selected funds, and detail the financial resources destined to each priority. An interactive interface enables the distribution of the budget

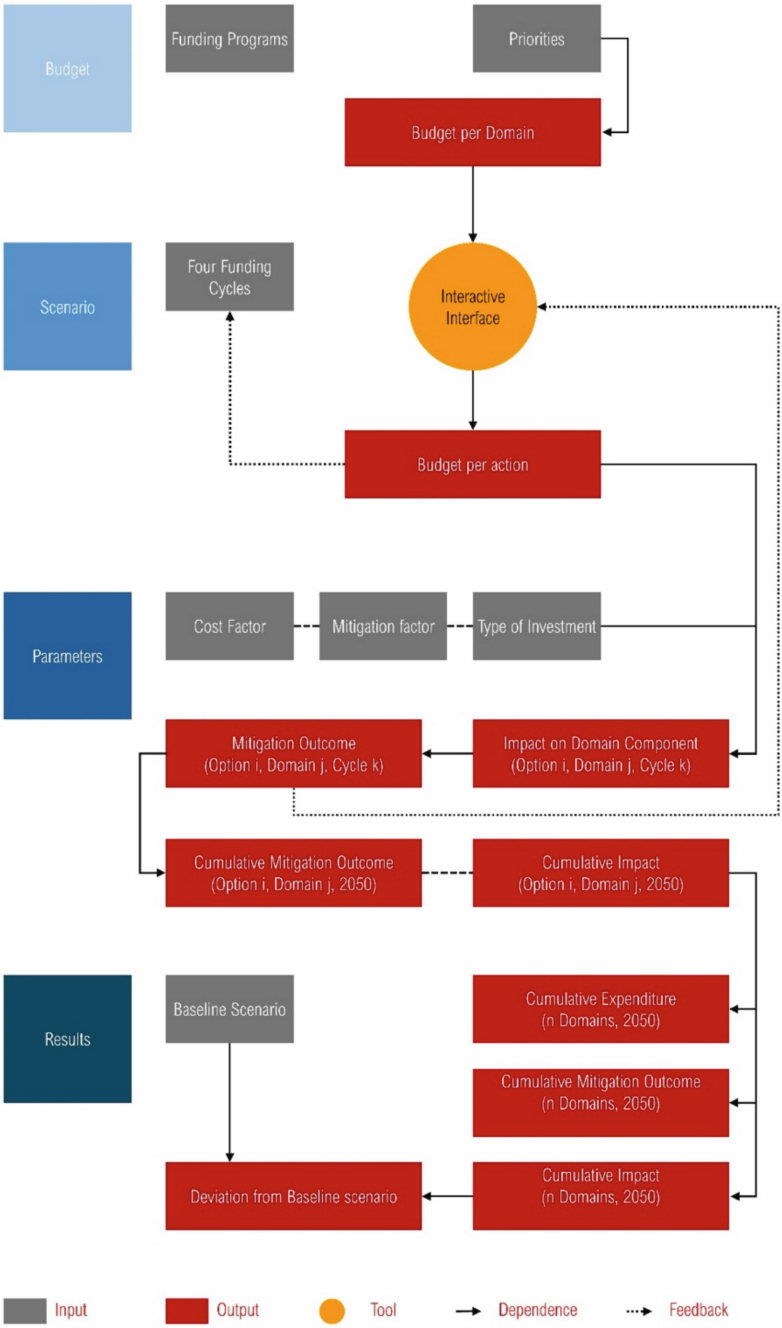

Fig. 1. Organization of the interactive tool for scenario modeling

destined to individual priorities among the IGC domains. For instance, the budget for Priority 1 under the FESR amounts to 229.2 M€. Priority 1 aims to promote innovation and the implementation of advanced technological solutions. The budget is distributed among the Agriculture domain (5%), Forest (5%), Water (5%), Transportation (25%), Energy (20%) and Urban (20%). Lastly, Sect. 4 indicates the budget destined to each dominion, resulting from the allocation optimization process implemented via the interactive interfaces included in Sects. 2 and 3. A chart represents the proportion of the total budget destined to each domain.

Parameters:
The parameters section details the input data used to create alternative adaptation and mitigation scenarios and implements the functions for estimating the mitigation outcome of each action for each time interval, considering the budget constraints and the allocation of funds to individual options, defined via the user interface in Sect. 3. The section is articulated on six sub-sections. Sect. 1 outlines the required input data, including the list of actions for a specific domain, the mitigation outcomes per unit of domain component, the cost per unit of domain component per year, the cost per unit of domain component per cycle, the indicator selected to measure the quantity of the relevant domain component targeted by the action, and the type of financing instrument. In case of capital expenditure programs, the service life of an action is considered equal to the duration of a cycle or a multiple thereof, with the entire funding provided at the start of the respective cycle. For subsidies, the cost per cycle is calculated by multiplying the annual cost per unit of the domain component by the duration of the cycle. Sub-Sects. 2–5 compute, for each cycle, the quantity of the domain component targeted by each action- given the cost and the funds destined to the action - and the relative mitigation output measured in metric tons of equivalent carbon dioxide per year. The input data are the mitigation and cost factors defined in sub-Sect. 1 and the funding destined to each action, as defined in Sect. 3. The mitigation outcome of the i-th action is computed by multiplying the mitigation factor, i.e. the respective mitigation outcome per year per unit of domain component, by the quantity of the domain component targeted by the action for the cycle considered. The impact of the action on the relevant domain component is computed by dividing the funding allocated to the action in the k-th cycle by the cost factor. Lastly, Sect. 6 details the cumulative quantity of domain components targeted and mitigation outcomes, measured in metric tons of equivalent carbon dioxide per year, resulting from the implementation of the proposed actions across the four cycles. For actions funded through capital expenditure programs, the quantity of the domain components targeted by the action and the resulting mitigation outcome are computed by considering the results of interventions whose service life has not expired by the end of the period considered. For options funded through subsidies, the cumulative outcomes in terms of mitigation and domain components adapted consider only the results of last cycle.

Scenario:
The scenario section represents the interactive interface used to develop alternative policy scenarios and to monitor the outcome, in terms of mitigation and quantity of domain components adapted, of distinct combinations of the proposed actions. A separate scenario section is provided for each domain. The section is organized into 5 sub-sections. Sect. 1 details the budget destined to the domain, which is considered constant across the

four cycles, the list of actions proposed for the domain, the cost factor and the mitigation factor of each action, and four columns representing each financing cycle. The columns fields are modifiable and enable the user to determine the proportion of the available budget destined to each action for each cycle. The funding destined to the i-th action for the j-th cycle represents the budget constraint considered in the domain parameters section for the computation of the quantity of the domain component targeted by the action and of the mitigation outcome. A fifth column details the cumulative budget allocated to the domain over four cycles, and the cumulative funding allocated to each action within the same period. A chart then details the ratio of the cumulative budget allocated to each action relative to the cumulative budget allocated to the domain. Sects. 2–5 present the results for each cycle in terms of mitigation, expenditure, and impact on the domain components. These results represent the output from specifying investment priorities, which lead to the distribution of funding among the actions as determined via the interactive interface. More precisely, for each cycle, the tool returns the cumulative mitigation outcome, measured in metric tons of equivalent carbon dioxide per year, the cumulative extent of domain components targeted and the relative percentage over the total extent of the relevant domain components, and the cumulative expenditure resulting from the combined implementation of the proposed actions over the considered cycle. A chart represents the ratio of the mitigation impact of each action to the cumulative mitigation output estimated for the considered cycle. Lastly, a histogram details, for each cycle, the proportion of funding destined to each action relative to the cumulative expenditure computed for the considered cycle.

Results:
The results section provides details for each domain over the four cycles, including cumulative expenditure, cumulative mitigation outcomes, and the percentage of each type of domain component targeted by the relevant actions. Moreover, the Target fields return the cumulative mitigation outcome over the eight domains and the four cycles and the resulting variation of equivalent carbon dioxide emissions compared to the baseline emission scenario. The cumulative mitigation outcome of the j-th domain is computed in the last sub-section of the Parameters page of the considered domain, as the sum, over the four cycles of the mitigation impact of each action. The mitigation impact of the i-th action is computed considering the funding destined to the action across the four cycles, its cost and mitigation factors and the service life of the embodied solutions. The baseline emission scenario represents the cumulative equivalent carbon dioxide emissions across the eight domains in 2022. These emissions are calculated by multiplying the estimated per capita carbon dioxide emissions in 2022 by the number of residents in the study area, in the same year. The input data are retrieved from the CIRO portal of the Italian National Institute for Statistics. Lastly, two histograms detail the distribution of the cumulative budget across the eight domains and the cumulative mitigation outcomes, over four cycles, of each domain, respectively. Moreover, two charts represent the proportion of the budget destined to each domain relative to the total available budget, and the percentage of cumulative mitigation outcomes, by 2050, for each domain. A final chart depicts the normalized impact of each domain on its respective components.

2.1 Definition of Mitigation and Cost Factors

A list of adaptation and mitigation options relevant to the application to the regional scale of the Impact model is defined via a four- step procedure: i) definition of domains requiring adaptation and mitigation actions; ii) definition of criteria and sub-criteria for categorizing options; iii) Selection of options based on criteria of relevance, feasibility and incidence. This preliminary selction is based on a review of options presented by the European Climate Adaptation Platform Climate-ADAPT, Italian National Strategies for Climate Change Adaptation (SNACC), Italian National Plan for Climate Change Adaptation (PNACC) and Intergovernmental Panel on Climate Change (IPCC) Assessment Reports 5 and 6; iv) Analysis and Comparative evaluation of pre-selected actions via a categorization system based on 16 criteria capturing general, functional and operation aspects of the actions identified in stage iii. The selected actions serve as data inputs for an interactive tool designed to enable the collaborative development of mitigation and adaptation scenarios, and to estimate the outcomes of alternative combinations of the actions. The list of adaptation and mitigation options, presented in the Climate actions handbook for Regional Adaptation Strategies in Basilicata includes 58 options: 8 options regard the Agriculture domain, 2 options the forest domain, 14 options are related to the Industrial sector, 6 options the transportation domain, 8 options concern the water domain, 4 the marine environment do-main, 8 the urban domain and 8 are related to the energy domain.

Building on the list of actions, the mitigation expected benefits and implementation costs are quantified based on a review of reports and scientific articles that investigate the selected actions. The determination of mitigation and cost factors is central to understanding the cost-benefit ratio of individual actions, which in turn is a fundamental parameter for optimizing the distribution of available funding among the selected options. Mitigation benefits include reduced levels of CO_2, NO_2, CH_4 emissions or release, and carbon sequestration. The determination of costs depend on the preliminary definition of the investment form. The latter refers to the nature and temporal aspects of financial instruments employed to incentivize action implementation. Single investments are directed toward the deployment of long-lasting structural measures. Capital renewal programs involve recurring financial allocations to support technological solutions with defined service lifespans, requiring systematic replacement or upgrading at set intervals. Compensatory mechanisms refer to financial incentives or subsidies intended to offset opportunity costs, profit losses, or maintenance expenditures associated with the adoption of alternative management practices, including both nature-based and engineered interventions. Concerning the agricultural sector, expected mitigation benefits are measured in terms of metric tons of equivalent carbon dioxide sequestered per year per unit of agricultural land surface area or in terms of equivalent carbon dioxide emissions saved per year per unit of agricultural land surface area. The estimated mitigation benefits range from a reduction of emissions of 0.024 tCO_2 $year^{-1}$ ha^{-1} resulting from the adoption of minimum soil disturbance practices to 4.95 t $year^{-1}$ ha^{-1} of equivalent carbon dioxide sequestered via the Conversion of arable land to grassland. A significant variability is observed regarding cost factors: Implementation costs per unit of agricultural land range from 20.4€ ha^{-1} per year, for Leaving crop residues on the soil surface, to 2500€ ha^{-1} per year for agroforestry practices (See Table 1).

Table 1. Mitigation and cost factors for the proposed actions relevant to the agriculture, forest, water and marine environment domains

Id	Action	Mitigation		Cost		Type
Agriculture (AG)						
001	Conversion of arable land to grassland	4.95	tCO_2yr^{-1} ha^{-1}	420	€ ha^{-1}	Investment
002	Minimum soil disturbance	0.024	tCO_2yr^{-1} ha^{-1}	380	€ yr^{-1} ha^{-1}	Compensation
003	Agroforestry	0.515	tCO_2yr^{-1} ha^{-1}	2500	€ ha^{-1}	Investment
004	Afforestation and Reforestation	1.65	tCO_2yr^{-1} ha^{-1}	866	€ ha^{-1}	Investment
005	Biological N fixation in rotations and in grass mixes	1.65	tCO_2yr^{-1} ha^{-1}	126	€ yr^{-1} ha^{-1}	Compensation
006	Leaving crop residues on the soil surface	1.16	tCO_2yr^{-1} ha^{-1}	20.4	€ yr^{-1} ha^{-1}	Compensation
007	Nutrient Management	0.071	tCO_2yr^{-1} ha^{-1}	282.5	€ yr^{-1} ha^{-1}	Compensation
008	Cover/ Catch Crops	1.175	tCO_2yr^{-1} ha^{-1}	165	€ yr^{-1} ha^{-1}	Compensation
Forest (FT)						
001	Sustainable/ Adaptive management of forest	0,37	tCO_2yr^{-1} ha^{-1}	280	€ yr^{-1} ha^{-1}	Compensation
002	Restoration of riparian buffers	0,051	tCO_2yr^{-1} ha^{-1}	4000	€ ha^{-1}	Investment
Water (WM)						
001	Water reuse	0.0803	tCO_2yr^{-1} inh^{-1}	368	€ inh^{-1}	Investment
002	Establishment and restoration of riparian buffers	0.051	tCO_2yr^{-1} ha^{-1}	4000	€ ha−1	Investment
003	Improved design of dikes and levees			35	€ m^{-3}	Investment
004	Improvement of irrigation efficiency	0.086	tCO_2yr^{-1} inh^{-1}	6416.7	€ inh−1	Capital Expenditure
005	Water restrictions and water rationing			35	€ yr^{-1} m^{-3}	Management
006	Protection and restoration of wetlands	2.000	tCO_2yr^{-1} ha^{-1}	4000	€ ha^{-1}	Investment
007	Increased connectivity of water infrastructure			10	€ m^{-3}	Investment

(*continued*)

Table 1. (*continued*)

Id	Action	Mitigation		Cost		Type
008	Water needs and concessions					Capital Expenditure
Marine Environment (ME)						
001	Integration of adaptation in coastal zone management plans	1.750	tCO_2yr^{-1} ha^{-1}	11188	€ ha^{-1}	Capital Expenditure
002	Risk-based zoning and siting for marine aquacolture	0.800	tCO_2 TPO−1	8068.2	€ TPO^{-1}	Capital Expenditure
003	Planning and management of areas close to marine protected areas	1.750	tCO_2yr^{-1} ha^{-1}	5000	€ ha^{-1}	Investment
004	Promote research on the effects of sea level rise			700000	€	Management

Moderate mitigation factors are estimated for actions relevant to the Water domain. In particular, the mitigation outcome per unit of domain component ranges from 0.051 tCO_2yr^{-1} ha^{-1} for the restoration of riparian buffers to $2tCO_2yr^{-1}$ ha^{-1} for options of Protection and restoration of wetlands. Cost are significant, hence limiting the cost-benefit ratio of the proposed actions and range from 35 € m^{-3} yr^{-1} for Improved design of dikes and levees to 6416.7 € per inhabitant for the Improvement of irrigation efficiency. Conversely, for the marine environment, mitigation factors range from $0.800tCO_2$ tPO^{-1} for the adaptation of marine aquaculture and fishing to $1.750tCO_2yr^{-1}$ ha^{-1} for Planning and management of areas close to marine protected areas. The cost-benefit ratio is negatively impacted by the elevated cost, equal to 11188€ ha^{-1}, 8068.2€ tPO^{-1} and 5000€ ha^{-1} for, respectively, Integration of climate change adaptation in coastal zone management plans, marine aquaculture and Planning and management of areas close to marine protected areas. Actions relevant to the forest domain present a moderate cost-benefit ratio resulting from moderate unitary mitigation outcome, equal to $0,37tCO_2yr^{-1}$ ha^{-1} and $0,051tCO_2yr^{-1}$ ha^{-1} respectively, for Sustainable/ Adaptive management of forest and Restoration of riparian buffers, and elevated costs, equal to 280€ yr^{-1} ha^{-1} and 4000€ ha^{-1}. Regarding the industry sector (Table 2), actions related to the optimization of production processes, including LDAR (Leak Detection And Repair), Reduced Venting and Electrification in up-stream oil and gas production, present a positive cost-benefit ratio with costs equal, respectively, to 0.92 € BOE^{-1}, 0.75 € BOE^{-1}, 1.92 € BOE^{-1} and unitary mitigation outcomes equal to 0.003 tCO_2 BOE^{-1} 0.002 tCO_2 BOE^{-1}, and 0.011 tCO_2 BOE^{-1}. Vice versa, measures specific to production-side decarbonization in the Concrete and steel industry, despite a significant mitigation potential – equal to $0.385tCO_2$ $tPO^{-1}$for Reduction of clinker content in cement and 0.535 tCO_2 tPO^{-1} for Carbon Capture Storage and Utilisation (CCS/ CCU) - present elevated costs. For instance, the cost per tonne of product is equal to 385 €

tPO^{-1} for reducing clinker content in cement and to 424.25€ tPO^{-1} for Carbon Capture Storage and Utilisation (CCS/ CCU).

Table 2. Mitigation and cost factors for options related to the Industry Domain

Id	Action	Mitigation		Cost		Type
Industry (IND)						
001	High-quality recycling of plastics	4.000	tCO_2 tPO^{-1}	3440	€ tPO^{-1}	Capital Expenditure
002	Use of biomass and CO2 as carbon input for polymers	4.500	tCO_2 tPO^{-1}	19260	€ tPO^{-1}	Capital Expenditure
003	Use of biomass as input for epoxy resins production	4.390	tCO_2 tPO^{-1}	38472	€ tPO^{-1}	Capital Expenditure
004	Recover/ Reuse	0.140	tCO_2 tPO^{-1}	210	€ tPO^{-1}	Capital Expenditure
005	Use of recycled clay brick powder (RBP) for mortar/ concrete	0.040	tCO_2 tPO^{-1}	39.9	€ tPO^{-1}	Capital Expenditure
006	Energy Optimization	0.067	tCO_2 tPO^{-1}	66.54	€ tPO^{-1}	Capital Expenditure
007	Alternative fuels (including biomass)	0.039	tCO_2 tPO^{-1}	36.1	€ tPO^{-1}	Capital Expenditure
008	Pre-treatment of alternative fuel	0.013	tCO_2 tPO^{-1}	15.89	€ tPO^{-1}	Capital Expenditure
009	Reduction of clinker content in cement	0.385	tCO_2 tPO^{-1}	385	€ tPO^{-1}	Capital Expenditure
0101	Carbon Capture Storage and Utilisation	0.535	tCO_2 tPO^{-1}	424.25	€ tPO^{-1}	Capital Expenditure
0102	Carbon Capture Storage and Utilisation	0.098	tCO_2 tPO^{-1}	42.48	€ tPO^{-1}	Capital Expenditure
0103	Carbon Capture Storage and Utilisation	0.017	tCO_2 BOE^{-1}	6.27	€ BOE^{-1}	Capital Expenditure
011	Biomass as input in EAF-based steel production Plants	0.015	tCO_2 tPO^{-1}	32.86	€ tPO^{-1}	Capital Expenditure

(*continued*)

Table 2. (*continued*)

Id	Action	Mitigation		Cost		Type
012	LDAR (Leak Detection And Repair)	0.003	tCO_2 BOE^{-1}	0.92	€ BOE^{-1}	Management
013	Reduced Venting	0.002	tCO_2 BOE^{-1}	0.75	€ BOE^{-1}	Capital Expenditure
014	Electrification	0.011	tCO_2 BOE^{-1}	1.92	€ BOE^{-1}	Capital Expenditure

Similarly, actions relevant ot urbanized areas entail elevated costs and mitigation outcomes. For instance, the reinforcement of urban green infrastructure, can sequester 8.29 tCO_2yr^{-1} ha^{-1} yet at a cost of 795100 € ha^{-1}. Implementing Climate smart urban agriculture could result in sequestering 2.20 tCO_2yr^{-1} ha^{-1} but the estimated cost amounts to 400000€ ha^{-1}. Positive cost-benefit ratio is observed, veice versa, regarding actions for the Transportation domain: Bike – Sharing, Optimization of transport logistics, Car – Sharing and Smart Roads, in particular, present a significant mitigation factor equal, respectively, to 0.080tCO_2 yr^{-1} inh^{-1}, 18tCO_2 yr^{-1} veh^{-1} 0.900tCO_2 yr^{-1} veh^{-1} and 0.745tCO2 yr^{-1} km^{-1} and a modest cost factor, amounting to 10.8€ inh^{-1}, 226.24€ Veh^{-1}, 112€ Veh^{-1}, and 5000€ Km^{-1} (See Table 3).

Table 3. Mitigation and cost factors of actions for the Urban, Transportation, and Energy domains.

Id	Action	Mitigation		Cost		Type
Urban (URB)						
001	Crises and disaster management systems and plans	0.051	tCO_2yr^{-1} ha^{-1}	4000	€ ha^{-1}	Investment
002	Urban green infrastructure planning and nature-based solutions	8.290	tCO_2yr^{-1} ha^{-1}	795100	€ ha^{-1}	Investment
003	Climate smart urban agriculture	2.200	tCO_2yr^{-1} ha^{-1}	400000	€ ha^{-1}	Investment
004	Using water to cope with heat waves in cities	18.000	tCO_2yr^{-1} ha^{-1}	40000	€ ha^{-1}	Investment

(*continued*)

Table 3. (*continued*)

Id	Action	Mitigation		Cost		Type
005	Co-located Housing and Jobs, Mixed Land Use	0.500	$tCO_2 yr^{-1}$ inh^{-1}	112	€ inh^{-1}	Investment
006	Avoiding, Minimising, and Recycling Waste	1.400	tCO_2 tPO^{-1}	5000	€ tPO−1	Capital Expenditure
007	Positive Energy or Energy Plus Buildings	1.620	$tCO_2 yr^{-1}$ inh^{-1}	7888,8	€ inh^{-1}	Capital Expenditure
008	Low-carbon Materials	17.850	tCO_2 inh^{-1}	114180	€ inh^{-1}	Management
Transport (TRANS)						
001	Climate-resilient railway infrastructure	0.00035	$tCO_2 yr^{-1}$ km^{-1}	1700000	€ Km−1	Investment
002	Climate resilient road infrastructure	0.034	$tCO_2 yr^{-1}$ km^{-1}	7500000	€ Km^{-1}	Investment
003	Bike - Sharing	0.080	$tCO_2 yr^{-1}$ inh^{-1}	10.8	€ inh−1	Capital Expenditure
004	Optimization of transport logistics	18.000	$tCO_2 yr^{-1}$ veh^{-1}	226.24	€ yr^{-1} Veh^{-1}	Management
005	Car - Sharing	0.900	$tCO_2 yr^{-1}$ veh^{-1}	112	€ Veh−1	Capital Expenditure
006	Smart Roads	0.745	$tCO_2 yr^{-1}$ km^{-1}	5000	€ Km^{-1}	Investment
Energy (EN)						
001	waste-to-energy (wte)	0.5	tCO_2 tPO^{-1}	1000	€ tPO^{-1}	Capital Expenditure
002	promotion of renewable sources and energy efficiency	0.414	tCO_2 MWh^{-1}	952	€ MWh^{-1}	Capital Expenditure
003	promotion of microgrid development	0.331	tCO_2 MWh^{-1}	1298.50	€ MWh^{-1}	Capital Expenditure
004	use of energy storage systems	0.414	tCO_2 MWh^{-1}	450000	€ MWh^{-1}	Capital Expenditure
005	use of flexible alternating current transmission systems	0.475	tCO_2 MWh^{-1}	89.04	€ MWh^{-1}	Capital Expenditure

(*continued*)

Table 3. (*continued*)

Id	Action	Mitigation		Cost		Type
006	agrivoltaic	0.414	$tCO_2\ MWh^{-1}$	740.74	€ MWh^{-1}	Capital Expenditure
007	bioenergy with carbon capture and storage (beccs)	5000000	tCO_2yr^{-1}	140	€/tCO2	Capital Expenditure
008	carbon capture technologies (ccs)	25000	tCO_2yr^{-1}	16000	€/tCO2	Capital Expenditure

Similarly, the cost-benefit ratio is positive for options related to the optimization of energy production and distribution. In particular, the promotion of renewable energy sources and energy efficiency, the development of microgrids, the use of flexible alternating current transmission systems (FACTS), and agrivoltaics could reduce emissions by 0.414 tCO_2 MWh−1, 0.331 tCO_2 MWh−1, 0.475 tCO_2 MWh−1, and 0.414 tCO_2 MWh−1, respectively. Costs are moderate, ranging from €89.04 MWh−1 for alternating current transmission systems to €1,298.50 MWh−1 for microgrid development (See Table 3). Conversely, technological options related to bioenergy with carbon capture and storage (BECCS) offer a significant mitigation potential, with the sequestration of up to 5,000,000 tCO_2 per year, but at a marginal abatement cost of €140.00 tCO_2 −1.

3 Implementation of the Interactive Tool

The proposed interactive tool has been utilized during the Basilicata Region Geo-design Workshop, developed in the framework of GD-CURE project on the specific case study of Basilicata Regional Climate Adaptation Strategy [8, 15, 16]. The workshop, held in December 2024, involved real stakeholders, technicians, researchers and NGO to approach a co-design session oriented to provide a spatial and place specific strategic masterplan for Climate actions [17]. The participants utilized the interactive tool for defining an optimal distribution of fundings provided by Regional Operating Programs (RP) including the European Regional Development Fund (ERDF) and European Social Fund plus (ESF +) and Rural funds (RDC) including the European Agricultural Guarantee Fund (EAGF), the European Agricultural Rural Development Fund (EARDF) and National and Regional Funds. The total available budget, over the four cycles, amounts to 3703.2 M€, equal to 925,8 per cycle. The total expenditure, over the four cycles, amount to 3680,2 M€, corresponding to 99.4% of the available budget. The cumulative expenditure for each domain amounts to 803.8 M€ for the Agriculture domain, 473.1 M€ for the Forest domain, 285.0 M€ for the Water domain, 101.0 M€ for actions relevant to the marine environment, 587.7 M€ for the Transportation sector, 738,6 M€ for the Energy sector, 401.4 M€ for urban areas and 289.7 M€ for actions related to Industrial production. In 2050, the cumulative mitigation outcome is projected to be 2,640 million metric tons of carbon dioxide equivalent per year saved, due to reduced emissions and carbon sequestration. With the estimated level of greenhouse gas (GHG) emissions in 2022 at

5,806 million metric tons of carbon dioxide equivalent per year, the implementation of the proposed actions is expected to determine a 55.33% reduction in GHG emissions compared to the baseline scenario. Transportation, Energy and Agriculture sectors contribute the most to mitigation outcomes: Measures related to the transportation sectors determine a reduction of GHG emissions per year equal to 1.946 $MtCO_2e\ y^{-1}$ (60.6% of the cumulative mitigation outcome) despite only representing 16% of the cumulative budget. Adaptation and mitigation actions specific to the Energy domain result in a reduction of GHG emissions equal to 0.534 $MtCO_2e\ y^{-1}$ (16.6% of the cumulative mitigation outcome) and account for 20.1% of the cumulative budget. Measures related to the Agriculture domain reduce GHG emissions by 0.333 $MtCO_2e\ y^{-1}$ (10.4% of the cumulative mitigation outcome) and account for 21.8% of the cumulative budget.

4 Conclusions

Based on the detailed arguments and findings presented in the paper, several key conclusions can be drawn at the level of operational improvement in tools supporting climate mitigation planning at regional scale, case study implementation and testing, main recommendations for future development of the research.

Emerging Tools for Climate Adaptation: The study highlights the increasing availability and utility of tools designed to support climate adaptation strategy formulation. These tools, exemplified by the integrated impact model developed within the GD-CURE project, demonstrate a critical advancement in supporting informed decision-making at various territorial scales. Specific tools have to be designed for specific application but the general criteria adopted in this specific research holds an extensive transferability and generalization potentials [18–20]. Integration of Local Actions: The paper underscores the importance of integrating local actions and investments into broader climate strategies. By adopting a multi-scale approach that incorporates local, national, and macro-regional perspectives, the GD-CURE framework facilitates Climate adaptation planning practices and decision making according to a clear defines small set of indicators and a basic input-output model running real-time on simple platform (simple spreadsheet). Impact and Effectiveness: The application of the integrated impact model to the Basilicata Region illustrates its effectiveness in simulating and evaluating climate adaptation and mitigation measures. By quantifying the potential impacts in terms of GHG emissions reduction and spatial coverage of intervention, stakeholders had the opportunity during a short geodesign workshop (less then 5 h) to optimize resource allocation and maximize environmental benefits [21–25]. This represents also a contribution in enhancing the Stakeholder Engagement and Participatory Processes [26–29]. Future Directions of the research and final recommendations regards the extension of testing the integrated impact model tool in other specific case studies. Between limitations of the approach and potentials, it is relevant to outline that the tool is strictly connected with the list of actions adopted as baseline for the Basilicata Region Case study. It is possible to affirm that even if this list changes the tools maintains its efficacy. In a general view, future research should reinforce the evidence-based link between scientific evidence, policy frameworks, and practical implementation will be essential for achieving ambitious climate targets across Europe and beyond [30–33].

References

1. Steinitz, C.: On change and geodesign. Landsc. Urban Plan. **156**, 23–25 (2016). https://doi.org/10.1016/j.landurbplan.2016.09.023
2. Steinitz, C., Orland, B., Fisher, T., Campagna, M.: Geodesign to address global change (2022). https://doi.org/10.1016/B978-0-12-820247-0.00016-3
3. Campagna, M.: Geodesign: (a Personal) Retrospective, and Perspectives (2024). https://doi.org/10.1007/978-3-031-54118-6_11
4. Abarca-Alvarez, F.J., Navarro-Ligero, M.L., Valenzuela-Montes, L.M., Campos-Sánchez, F.S.: European strategies for adaptation to climate change with the mayors adapt initiative by self-organizing maps. Appl. Sci. **9**, 3859 (2019). https://doi.org/10.3390/app9183859
5. Wendler, F.: Climate change policy in the EU: from the Paris agreement to the European green deal. In: Wendler, F. (ed.) Framing Climate Change in the EU and US After the Paris Agreement, pp. 65–117. Springer International Publishing (2022). https://doi.org/10.1007/978-3-031-04059-7_3
6. Steininger, K.W., Williges, K., Meyer, L.H., Maczek, F., Riahi, K.: Sharing the effort of the European Green deal among countries. Nat. Commun. **13**, 3673 (2022). https://doi.org/10.1038/s41467-022-31204-8
7. Mysiak, J., et al.: Climate risk index for Italy. Philos. Trans. R. Soc. Math. Phys. Eng. Sci. **376** (2018). https://doi.org/10.1098/rsta.2017.0305
8. Scorza, F.: Training Decision-Makers: GEODESIGN Workshop Paving the Way for New Urban Agenda (2020). https://doi.org/10.1007/978-3-030-58811-3_22
9. Campagna, M.: Metaplanning: about designing the geodesign process. Landsc. Urban Plan. **156**, 118–128 (2016). https://doi.org/10.1016/J.LANDURBPLAN.2015.08.019
10. Campagna, M.: Geodesign a-to-z: evolution of a syllabus for architects and engineers. J. Digit. Landscape Archit. 271–278 (2017). https://doi.org/10.14627/537629028
11. Moura, A.C.M., Campagna, M.: Co-design: Digital tools for knowledge-building and decision-making in planning and design. DISEGNARECON. 11, ED.1-ED.3 (2018)
12. Campagna, M.: Geodesign A-to-Z: Evolution of a syllabus for architects and engineers. J. Digit. Landscape Archit. https://doi.org/10.14627/537629028
13. Annunziata, A., et al: Climate actions handbook supporting decision making for regional adaptation strategies in Basilicata, Italy. In: Gervasi, O., Murgante, B., Garau, C., Karaca, Y., Lago, M.N.F., Scorza, F., and Braga, A. (eds.) 25th International Conference on Computational Science and Its Applications (ICCSA 2025). Springer Nature Switzerland AG, Istanbul, Türkiye (2025)
14. Scorza, F., Saganeiti, L., Pilogallo, A., Murgante, B.: Ghost planning: the inefficiency of energy sector policies in a low population density region1. ARCHIVIO DI STUDI URBANI E REGIONALI, 34–55 (2020). https://doi.org/10.3280/ASUR2020-127-S1003
15. Moura, A.C.M., Campagna, M., Poplin, A., Rivero, R.G., Scorza, F.: Geodesign education: case studies from the US. Brazil and Italy (2023). https://doi.org/10.1007/978-3-031-37114-1_18
16. Scorza, F., Santopietro, L., Corrado, S., Dastoli, P.S., Santarsiero, V., Gatto, R., Murgante, B.: Training for Territorial Sustainable Development Design in Basilicata Remote Areas: GEODESIGN Workshop. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 13379 LNCS, pp. 242–252 (2022). https://doi.org/10.1007/978-3-031-10545-6_17/COVER
17. Iula, G., et al.: Paving the way to basilicata climate adaptation strategy: a GeoDesign workshop. In: Gervasi, O., et al. (eds.) 25th International Conference on Computational Science and Its Applications (ICCSA 2025). Springer Nature Switzerland AG, Istanbul, Türkiye (2025)

18. Scorza, F.: Towards self energy-management and sustainable citizens' engagement in local energy efficiency agenda. Int. J. Agric. Environ. Inf. Syst. (IJAEIS). **7**, 44–53 (2016). https://doi.org/10.4018/ijaeis.2016010103
19. Santopietro, L., Solimene, S., Lucchese, M., Di Carlo, F., Scorza, F.: An economic appraisal of the SE(C)AP public interventions towards the EU 2050 target: the case study of Basilicata region. Cities. **149** (2024). https://doi.org/10.1016/j.cities.2024.104957
20. Dvarioniene, J., Grecu, V., Lai, S., Scorza, F.: Four perspectives of applied sustainability: Research implications and possible integrations. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). 10409 LNCS, pp. 554–563 (2017). https://doi.org/10.1007/978-3-319-62407-5_39
21. Annunziata, A., Scorza, F., Corrado, S., Murgante, B.: Unveiling intra-rural divides: investigating decline and prosperity in rural areas. the case study of southern Italy. Eur. Planning Stud. **32**, 1478–1505 (2024). https://doi.org/10.1080/09654313.2024.2335312;WGROUP:STRING:PUBLICATION
22. Gatto, R.V., Corrado, S., Scorza, F.: Towards a definition of tourism ecosystem. In: 18th International Forum on Knowledge Asset Dynamics (IFKAD) - Managing Knowledge For Sustainability (2023)
23. Gatto, R.V., Corrado, S., Scorza, F.: Taxonomy for specialized tourism ecosystems : new geographies for sustainable territorial planning. Habitat Int. (2025)
24. Scorza, F.: Improving EU cohesion policy: the spatial distribution analysis of regional development investments funded by EU structural funds 2007/2013 in Italy. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), pp. 582–593 (2013). https://doi.org/10.1007/978-3-642-39646-5_42
25. Las Casas, G., Scorza, F., Murgante, B.: Conflicts and sustainable planning: peculiar instances coming from Val D'agri structural inter-municipal plan. In: Papa, R., Fistola, R., and Gargiulo, C. (eds.) Smart Planning: Sustainability and Mobility in the Age of Change, pp. 163–177. Springer (2018). https://doi.org/10.1007/978-3-319-77682-8_10
26. Scorza, F., Pontrandolfi, P.: Citizen participation and technologies: the C.A.S.T. architecture. In: Gervasi, O., et al. Computational Science and Its Applications -- ICCSA 2015. ICCSA 2015. Lecture Notes in Computer Science(), vol. 9156, pp. 747–755. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-21407-8_53
27. Scorza, F., Fortunato, G., Carbone, R., Murgante, B., Pontrandolfi, P.: Increasing urban walkability through citizens' participation processes. Sustainability. **13**, 5835 (2021). https://doi.org/10.3390/su13115835
28. Cocco, C., Jankowski, P., Campagna, M.: An analytic approach to understanding process dynamics in geodesign studies. Sustainability **11**, 4999 (2019). https://doi.org/10.3390/su11184999
29. Somma, M., Campagna, M., Canfield, T., Cerreta, M., Poli, G., Steinitz, C.: Collaborative and sustainable strategies through geodesign: the case study of Bacoli. In: Gervasi, O., Murgante, B., Misra, S., Rocha, A.M.A.C., Garau, C. (eds.) Computational Science and Its Applications – ICCSA 2022 Workshops. ICCSA 2022. Lecture Notes in Computer Science, vol. 13379, pp. 210–224. Springer, Cham (2022). https://doi.org/10.1007/978-3-031-10545-6_15
30. Santopietro, L., Scorza, F.: Voluntary planning and city networks: a systematic bibliometric review addressing current issues for sustainable and climate-responsive planning. Sustainability **16** (2024). https://doi.org/10.3390/su16198655
31. Scorza, F., Fortunato, G.: Active mobility-oriented urban development: a morpho-syntactic scenario for a mid-sized town. Eur. Planning Stud. 1–25 (2022). https://doi.org/10.1080/09654313.2022.2077094

32. Gatto, R.V., Scorza, F.: Tourism ecosystem domains. In: Gervasi, O. (ed.) Computational Science and Its Applications - ICCSA 2023. Springer (2023)
33. Scorza, F., Gatto, R.V.: Identifying territorial values for tourism development: the case study of Calabrian Greek Area. Sustainability **15**, 5501 (2023). https://doi.org/10.3390/SU15065501