Climate Actions Handbook Supporting Decision Making for Regional Adaptation Strategies in Basilicata, Italy

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Abstract. This study presents the development of a climate actions handbook to support decision-making for regional adaptation strategies in the Basilicata Region, Italy. Through a multi-step methodology based on scientific literature and policy review, the research outlines a taxonomy of 58 adaptation and mitigation options across eight domains: Agriculture, Forest, Industry, Water, Marine Environment, Transport, Urban Areas, and Energy. Actions were evaluated and categorized according to 16 general, functional, and operational criteria, including cost-effectiveness, relevance to climate drivers and impacts, co-benefits, governance levels, and implementation scales. The result is a comprehensive and adaptable framework designed to guide stakeholders in prioritizing interventions based on contextual needs and resource constraints. This tool supports evidence-based and participatory planning processes, contributing to the long-term sustainability of regional climate adaptation strategies.

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

1 Introduction

The objective of the study is the definition of a taxonomy of adaptation and mitigation actions relevant to improving climate resilience in the Basilicata region, in Italy. The research is a component of a wider application titled GD-CURE "*GeoDesign for Climate URban nEutrality"* aiming to develop effective tools and methods to support territorial governance in climate change mitigation, adaptation, and the green transition [1–3]. Adopting a multi-scale approach, the project integrates local, national, and macro-regional perspectives into sustainable urban and territorial development strategies. Global climate change policies recognize local adaptation strategies as key for implementing interventions, promoting a "positive-sum" approach through lists of potentially adoptable actions. Within this framework, we focus on the regional scale, supporting the design of a regional adaptation strategy by testing the "Climate Actions Handbook" in the Basilicata Region case study.

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While the European Union has significantly reinforced its commitment through key frameworks such as the Paris Agreement and the European Green Deal [4], setting out targets that require the proactive engagement of public authorities at all levels of governance [5–7], in Italy, the National Climate Change Adaptation Strategy (SNAC), adopted in 2015, constitutes the main national initiative for addressing climate adaptation. Italian Regions have shown uneven commitment to climate change adaptation, resulted in fragmented, heterogeneous strategies, often embedded in broader sustainability agendas. Those considerations make the regional scale case study representative of an analytical process transferable to the implementation context as DSS. This research proposes a taxonomy constructed via an extensive literature review, articulated on 4 steps: 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; iv) Description of selected actions, comparison and Refinement of actions selection. The resulting categorization system is a relevant, replicable and understandable tool for the description, evaluation and comparison of mitigation/adaptation options. It is conceived as a conceptual frame aimed at enabling informed decisions in the selection of relevant actions for developing adaptation plans at distinct scales, from the local to the national and regional levels.

1.1 Domains Selection and Selection Process

The domains considered are defined based on the International Geodesign Collaboration (IGC) Global Climate Geodesign Challenge (GC) and include: Energy, Agriculture, Forest, Ocean, Settlement, Industry, Transportation and Water [7–9]. Relevant actions are selected based on criteria of relevance, feasibility and adequacy. Relevance refers to: i) the presence and size of domain components targeted by an action: for instance, the presence and extent of land cover/ land use types, infrastructures, production activities relevant to a specific action; and ii) the incidence of climate alteration impacts and drivers mitigated by the action: for instance the incidence of temperature increase, aridity, precipitation decrease, frequency of extreme events. Feasibility refers to cost-benefit balance, potential of maladaptation and socio-institutional limiting factors, including regulations, implementation of funding solutions, resistance to adopting alternative practices. Adequacy refers to potential benefits in terms of mitigation, adaptation and sustainable development; in particular, actions providing both adaptation and mitigation benefits are prioritized. The first stage of the selection process is conducted via 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) [10] and Intergovernmental Panel on Climate Change (IPCC) Assessment Reports 5 and 6 [11–15]. The second stage of the selection process is based on a review of reports of international organizations, policy documents and scientific articles. It is aimed at complementing information on measures identified in the first stage. As a result, Stage 1 is crucial for outlining the strategic and scientific base for evaluating potential adaptation and mitigation options; it relies on influential platforms and policies to ensure that the actions proposed are aligned to the latest scientific findings and strategic directions in climate adaptation and mitigation. Regarding the fundamental references used in stage 1, Climate-ADAPT is a collaborative initiative

between the European Commission and the European Environment Agency (EEA). It is managed by the EEA and the European Topic Centre on Climate Change Adaptation and LULUCF (ETC/CA). The IPCC is an organization of governments created in 1988 by the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP). Its purpose is to equip governments at all levels with the scientific information required to formulate climate policies. IPCC reports represent a fundamental input for global negotiations on climate alterations. The organization comprises member governments from the United Nations and the WMO, totaling 195 members. For the assessment reports, experts review scientific papers to summarize findings on the causes of climate change, its potential impacts, and strategies for adaptation and mitigation. The Italian SNACC [16] is a policy strategy document formulated in 2014 under the supervision of the Euro-Mediterranean Center on Climate Change (CMCC). Lastly the selected actions are categorized and described based on criteria and sub-criteria identified at step 2 and evaluated. After a comparison actions can be retained or removed from the proposed list. Actions are removed in case of concerns related to adequacy, maladaptation, feasibility or relevance or in case of absence of information relevant to describing the actions in relation to at least 25% of selected criteria.

2 The Categorization System

The proposed categorization system represents an output of the study. It structures a concise and detailed descriptions of selected actions, functional to understanding, evaluating and comparing proposed options and to facilitating informed decisions in the context of developing climate related plans. The categorization system is based on 16 criteria and 4 descriptive items. The 16 criteria are divided in general, functional, and operational. General criteria include Strategy, Purpose, IPCC categories and Type of actions. Strategy refers to the perspective embodied in the option. An option can be defined as hard, if entailing engineered solutions, infrastructural interventions or alterations in land use/ land cover and as soft if based on transformation of practices, policies or informational/ educational actions. Purpose refers to the general aim of the action: Adaptation measures are aimed at reducing exposure and vulnerability to climate alteration impact and at improving resilience; Mitigation options are aimed at limiting greenhouse gasses (GHG) emissions or at reducing GHG levels in atmosphere; Mitigation/ Adaptation options produce benefits in terms of both reducing GHG emissions or reducing GHG levels and increasing resilience and adaptive capacity of natural, social and economic systems. IPCC categories discern options based on the instruments and scope of the action [17]. Structural options refer to discrete actions presenting clear outputs and outcomes and clearly defined in scope, space and time. Structural options include engineering measures, technological solutions, use of ecosystem services to realize adaptation/ mitigation goals and the provision of specific services at the national, regional or local levels. Social options refer to soft actions aimed at increasing the adaptive capacity of social systems, reducing social inequities and the vulnerability of disadvantaged groups. Social options can be grouped in distinct categories: education is conceived as a public good to promote dialogue and engagement to enable the development of resilience at the level of the individual learner and of the socio-ecological system; information

refers to actions including scenario development, computer modelling, monitoring and remote sensing aimed at fostering response to natural events by individual and responsible institutions. Practices options refer to the adoption of alternative practices, including modes of living and forms of production. Institutional options include economic instruments, Regulations and policies, plans and programs developed by institutions at the national, regional and local levels for regulating and managing land use and land use transformations, and socio-economic activities to reduce vulnerability and exposure of socio-ecological systems, foster the implementation of social and structural options, and sustaining post-disaster recovery. Types of actions refers to the principal mode of intervention embodied in an option. For instance, Nature-based solutions include blue options and green options, Behavioural options include capacity building, modification of practices, and optimizing operations; Government policies and programs can be implemented via Management and Plans, Policy instruments, and Urban upgrading programs. Functional criteria include Relevance to climate alteration impacts, relevance to climate alteration drivers, Potential Benefits, Performance indicators, Cost indicators and Incidence indicators. Relevance to climate alteration impacts refers to the natural hazards in relation to which an action reduces the vulnerability and/ or exposure of a socio-ecological system. Impacts relevant to the area of study include average temperature increase, heatwaves, precipitation decrease, extreme precipitation events, pluvial floods, landslides, aridity, droughts, land degradation, fire weather, decline in wind speed, reduced frequency and increased intensity of storms, coastal erosion, and compound flood events resulting from a combination of extreme sea level and extreme precipitation events. Relevance to Climate alteration drivers refers to species of GHGs whose emissions or concentration levels are reduced by an option. The species of GHG emissions considered include carbon dioxide (CO_2), methane (CH_4) and Nitrogen dioxide (NO_2). Potential benefits refer to the estimated positive outcomes resulting from implementing an action. Benefits in terms of adaptation include conservation of natural resources, preventing deforestation, reducing soil erosion, improved soil fertility, preserving bio-diversity, improved climate resilience, micro-climate regulation, water regulation, reduced flooding, wind speed regulation, improved air quality, optimization of energy use and reduced disaster risk. Mitigation benefits include reduced levels of CO_2, NO_2, CH_4 emissions or release, and carbon sequestration. Socio-economic benefits include maintaining levels of production, improved socio-economic stability, cost reduction, improved quality of life, creation of public space, and reduced incidence of non-communicable diseases. Performance indicators are defined based on available scientific articles on the selected options and refer to metrics utilized to evaluate the positive outcomes, resulting from implementing an option.

Selected metrics include carbon dioxide equivalent sequestered (C-SEQ), Reduction of carbon dioxide equivalent emissions (RED-C) for measuring mitigation benefits, and Reduction of costs related to climate related impacts (COST-RED) as a metric of adaptation benefits. Cost indicators refer to metrics relevant to estimating the demand of financial resources required for implementing/ managing an option and include implementation costs (IC), maintenance costs (MC), loss of profits (LOP) and marginal abatement costs (MAC). Incidence indicators refer to metrics used to evaluate the quantity of

domains components targeted by a specific action, given a cost factor and budget constraints. Variables considered include cropland surface area (CSA), natural land surface area (NSA), Industrial production output (TPO), urban land surface area (ULSA), extent of infrastructural systems (L), number of residents (INH), number of vehicles (VEH) and energy output (TEO). Operational criteria include time frame, scale of implementation, governance level, cost-benefit balance, potential of maladaptation and form of investment. Time frame refers to the time required for implementing an option or to the estimated date for initiating the implementation of an option. Scale of implementation refers to the territorial level relevant to the implementation of an action. For instance, regulations concerning climate proofed standards for infrastructure design are implemented at a national scale. Vice versa, actions concerning agricultural land, including, for instance, Conversion of arable land to grassland, Minimum soil disturbance and Agroforestry are implemented at a local scale. Governance level refers to the institutional level responsible for developing plans, programs, regulations and financial instruments aimed at incentivising/ promoting the implementation of an action. The identified levels are: local (municipalities, provinces), regional (Regional Government, regional agencies), and State-level (ministries, national agencies). Cost-benefit balance refers to the capacity of an action to produce the greatest advantage in relation to its cost; as a result, it captures the feasibility of an action and is evaluated via a categorial variables presenting values ranging from low, to average, and to significant. An analogous categorial variable is used to measure the criterion Potential of maladaptation. Maladaptation refers to actions leading to undesired increase in risk of climate related negative outcomes, resulting from increased GHG emissions, increased or transferred vulnerability to climate alteration, and inequities outcomes. Lastly, investment form refers to the type and temporal dimension of financial instruments utilised to incentivise the implementation of an action. Single investment refers to funding solutions utilised to support the implementation of permanent structural options; Capital Renewal Programs refer to funding solutions utilised to support the implementation of technological options presenting a limited service life and requiring replacement at predefined time intervals. Lastly compensations refer to subsidies or incentives utilised to compensate loss of profit or maintenance costs resulting from the adoption of alternative practices or management of nature-based and engineered options.

3 Selected Actions

The proposed list of actions 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 domain, 8 the urban domain and 8 are related to the energy domain. In the subsequent sections the article describes the complexity of the list of actions by presenting the scope of the domains considered, and for the domain Agriculture by presenting the complete list of actions and a detailed description of selected option.

3.1 Agriculture

Climate alterations are impacting agricultural systems, determining negative consequences on life conditions, food security, and nutrition. Human-induced increase of average temperature results in displacement and composition modification of biomes, Reduced suitability for typical crops, and variation in Crop phenology and development season duration. Heat waves impact the pollen viability, fertilisation and grain or fruit formation. Drought results in increased irrigation demand, land degradation, decreased Photosynthesis and reduced nutrient absorption and consequently in impaired flowering and fruit set and Susceptibility to pests and diseases. Lastly, Intense precipitationcan determine anoxic conditions that impair roots development, plant damage, soil erosion, exposure to diseases, and delayed harvest and planting. The impacts of climate alteration are determining decrease in crop yield and in grassland productivity, crop damage, reduced animal productivity, decline in product quality and loss of arable land.

The options proposed for the agriculture domain include Conversion of arable land to grassland [18], Minimum soil disturbance [18], Agroforestry [19], Afforestation and Reforestation [18], Biological N fixation in rotations and in grass mixes [18], Leaving crop residues on the soil surface [18], Nutrient Management [20], and Cover/ Catch Crops [18].

3.2 Forest

Regarding the Forest domain, multiple studies and trends observed in multiple regions lead to consider numerous observed alterations in the ranges, phenology, physiology and morphology of terrestrial and freshwater species as a consequence of regional and global climate changes, particularly increases in the frequency and severity of extreme events. Climate alteration and extreme events are also related to increases in disease severity, outbreak frequency and emergence of new vectors. Increased temperature, drought and aridity are related to increased risk of wildfire and tree-mortality [21]. These impacts result, in turn, in the risk of carbon stored in the biosphere being released in the atmosphere. Projected trends reveal that climate alterations will result in a general reduction in the provision of regulating ecosystem services, including carbon storage, and regulation of freshwater quantity and quality, and a general increase in climate-related hazards, particularly in an increase in the number of fires and burnt areas [22]. As a result the options proposed for the forest domain include sustainable adaptive management of forest and restoration of riparian buffers [18]. In particular, Sustainable/ Adaptive management of forests consists of longer rotations, less intensive harvests, continuous cover forestry, mixed stands, more adapted species, and restoration or creation of protected areas, new habitats, and corridors among habitats.

3.3 Industry

Emissions from the industrial sector have increased faster than emissions from any other sector, driven by increased basic materials extraction and production. In 2019, greenhouse gas (GHG) emissions from the industrial sector, originating from fuel combustion, industrial processes, product use, and waste, amounted to 14.1 $GtCO_2$-eq, representing

24% of all direct anthropogenic emissions, second only to the energy transformation sector. When including indirect emissions from electricity and heat production, the industrial sector becomes the largest contributor, responsible for 20 $GtCO_2$-eq or 34% of global emissions. Notably, emissions from direct fuel combustion have declined, accounting, in 2019, for 7 $GtCO_2$-eq [23]. A significant contribution to mitigating industrial sector emissions can derive from reducing emissions in GHG–intensive industries, particularly cement, steel, plastics, and ammonia. Main decarbonization strategies focus on energy efficiency, the reduction of the need for primary production via reduced material demand, materials efficiency and circular economy, and production decarbonization; the latter is based on the use of low to zero-GHG energy carriers and feedstocks such as electricity, hydrogen, biofuels, and carbon capture and utilisation (CCU) for carbon-based feedstocks and carbon capture and storage (CCS) for residual CO_2 [24]. Consequently, the proposed actions focus on mitigation options targeting GHG-intensive industrial sectors located in the Basilicata region, namely, steel production, cement production, plastics manufacturing, and oil and gas extraction. Measures proposed for the Industry domain include 14 options, namely High-quality recycling of plastics [25], Use of biomass and CO2 as carbon input for polymers [26], Use of biomass as input for epoxy resins production [24], Recover Sand Granulate and unused cement [25], Use of recycled clay brick powder (RBP) for mortar/ concrete [27], Energy Optimization [28], Alternative fuels (including biomass)[29], Pre-treatment of alternative fuel [30], Reduction of clinker content in cement [30], Carbon Capture Storage and Utilisation (CCS/ CCU) [30], Biomass as input in EAF-based steel production Plants [31], LDAR (Leak Detection And Repair) [32], Reduced Venting and Electrification [33, 34].

3.4 Water

The water sector is affected by multiple climate change-related impacts. In southern Europe, pluvial flooding and flash floods, determined by intense rainfall, account for the majority of flood events. Extreme precipitation events are projected to become more frequent and severe. Coupled with increasing urbanisation, this trend is expected to elevate the risk of pluvial flooding [35]. Southern Europe is also susceptible to more severe and persistent water scarcity and droughts. At 1.5 °C GWL, the number of days with water scarcity - defined as inadequate water availability relative to demand and drought is projected to increase moderately [36]. Under these conditions, 18% of the population would face at least moderate water scarcity, rising to 54% at 2 °C GWL. Climate change also amplifies the effects of non-climatic hazards such as overexploitation, excessive water abstraction, nutrient enrichment, and pollution. These combined pressures reduce the resilience of biota and ecosystems, contributing to habitat loss and fragmentation, as well as the decline or local extinction of thermosensitive species [37].

Creation and restoration of riparian buffers id identified as an option relevant to increasing climate resilience and mitigation in the Basilicata Region. Riparian buffer strips are vegetated zones along rivers that provide flood prevention, drought mitigation, and water cooling. Riparian buffers mitigate flooding by regulating water flow, increase drought resilience through enhanced groundwater recharge, and lower water temperatures through shading. Further measures include Water reuse [38], Improved design of dikes and levees [39], Improvement of irrigation efficiency [40], Water restrictions and

water rationing [41], Protection and restoration of wetlands to mitigate the salinization of soils and aquifers in coastal areas [42], and Increased connectivity of water infrastructure [10].

3.5 Marine Environment

Impacts of climate alteration on the Marine Environment in the Mediterranea region include Sea surface warming between 0.25 °C and 1 °C [35], salinity alteration, acidification resulting in a mean decrease of surface pH of about 0.1 and 0.3 pH units at 1.5 °C and 3 °C Global Warming Levels (GWL) [43] – and sea level rise (SLR). If adaptation measures are inadequate, coastal flooding in Europe is projected to increase due to SLR intensified by storm surges, rainfall and river runoff [44, 45]. Moreover, SLR is expected to accelerate the erosion of sandy coastlines, leading to a shoreline retreat of about 100 m under a 4 °C GWL [35]. Consequently, actions proposed for the Marine environment include Integration of climate change adaptation in coastal zone management plans [46], Diversification of fisheries and aquaculture products and systems [47], Planning and management of areas close to marine protected areas [48] and Promote research on the effects of sea level rise.

3.6 Transportation

In 2019, the transport sector released 8.9 Gt of carbon dioxide equivalent (CO_2eq), a significant increase from 5.1 GtCO_2eq in 1990. Globally, transport was the fourth largest source of GHG emissions. The sector accounted for around 15% of total GHG emissions and 23% of energy-related CO_2 emissions. Over the past two decades, transport-related emissions have increased rapidly, with an average annual increase rate of 1.8% since 2010: Hence the transport sector emerges as the fastest-growing source of emissions among end-use sectors. Reducing emissions from transport is central to national and global GHG mitigation strategies, particularly as it is the principal energy-consuming sector in 40% of countries. As of 2019, the primary contributor to transport emissions was road transport, including both passenger and freight movement, accounting for 6.1 GtCO_2-eq or 69% of the sector's total emissions. On-road transport thus represent the dominant source of transport-related CO_2 emissions and present the greatest potential for mitigation [49]. As a result, the measures proposed for the Transportation domain include Climate-resilient railway infrastructure, Climate proofed standards for road design, construction and maintenance, Use of Bike-sharing systems [50], Optimization of transport logistics [49], Use of Car-sharing systems [51], and Smart Roads [52]. Proposed actions are relevant to mitigating emissions from the transport sector, in particular in urban areas. Vehicular transportation, in fact, produces 78% of emissions in urban areas and up to 70–80% of NO_2 emissions. Moreover, the implementation of alternative transportation modes is complementary to land-use zoning options and interventions of socio-spatial reorganization of urbanized areas relevant to increasing resilience in cities [50].

3.7 Settlements

Cities and trends of Urbanisation produce interdependent effects relevant to climate alteration. Urban areas have emerged as major contributors to GHG emissions [50], and are becoming increasingly vulnerable and exposed to the impacts of climate alteration. The urban contribution to global emissions is substantial and increasing, rising from 25 $GtCO_2eq$ in 2015 to 29 $GtCO_2eq$ in 2020, representing between 62% and 72% of the global total. Urban emissions are influenced by structural qualities of cities, such as urban form, density, and size. As a result, changes in land use and urban design influence future environmental impacts and the potential for long-term mitigation.

Moreover, the interaction between urban form, climate exposure and vulnerability, and direct climate impacts can result in context-specific risks for individual cities [17]. For example, rising temperatures driven by climate change can intensify the adverse effects of the urban heat island (UHI) phenomenon [53]. Cities are also increasingly exposed to river, pluvial, sewer, and coastal flooding, exacerbated by both rising global temperatures and urban structural transformations such as land-use conversion and soil sealing [54]. Strategies for urbanised areas include 8 options, namely Crises and disaster management systems and plans [50], Urban green infrastructure planning and nature-based solutions [50], Climate smart urban agriculture, using water to cope with heat waves in cities [50], Co-located Housing and Jobs and Mixed Land Use [55], Avoiding, Minimising, and Recycling Waste [56], Positive Energy or Energy Plus Buildings, and Low-carbon Materials [50]. The Creation of Urban green infrastructure is recognized as a fundamental option for realizing mitigation, adaptation and sustainable development goals in urbanized areas: it aims to create continuous and multi-functional systems of green and blue spaces in cities, providing environmental, social, and economic benefits and improving climate resilience.

3.8 Energy

The energy domain is the largest contributor to CO_2 emissions. In the time period 2015–2019, fossil fuel CO_2 emissions from the global energy system increased by 4.6% (an average of 1.1% per year), reaching 38 $GtCO_2$ annually and contributing two-thirds of total global anthropogenic GHG emissions. Reducing energy sector emissions is central to limiting climate alterations. Under scenarios limiting GWL to 1.5 °C Energy sector CO_2 emissions are expected to decline by 87–97% by 2050 and 60–79% in scenarios limiting GWL to 2 °C, with action starting in 2020. Energy sector GHG emissions are expected to decrease by 85–95% under scenarios limiting GWL to 1.5 °C, and 62–78% under scenarios limiting warming to 2 °C with action starting in 2020. By 2030, under scenarios limiting warming to 1.5 °C the expected decrease in net CO2 and GHG emissions amounts to, respectively, 35–51% and 38–52% [57]. Proposed Adaptation/ Mitigation strategies of the energy domain in the Basilicata Region are based on eight options including Waste-To-Energy (WTE) [57], Renewable sources and energy efficiency [10], Microgrid development [10], Energy storage systems [57], Flexible alternating current transmission systems [58], Agrivoltaic Systems [59], Bioenergy with carbon capture and storage (BECCS) [60], and Carbon Capture Technologies (CCS)[60].

4 The Handbook

The Handbook is a knowledge-based tool, designed to guide the identification and spatialization of climate change mitigation and adaptation measures across diverse sectors, defined based on the IGC Global Climate Geodesign Challenge Domains. It offers a systematic approach to help users easily understand the proposed actions through a well-structured key section, based on the criteria outlined in the categorization system. Lastly, the referenced sources ensure that the information is based on reliable scientific studies. This makes the tool highly practical for decision-makers or any stakeholders involved in the process of strategic climate mitigation design, enabling them to assess which climate strategies align most effectively with their regional and local needs. Furthermore, the actions are grouped into broader categories, reflecting their over-arching roles in climate resilience and sustainability, which supports a comparative assessment across sectors. The Handbook is designed with user accessibility in mind in the geodesign work-shop and is available online through the GD-CURE project website (https://prin.unica.it/gd-cure/). These features enable stakeholders to easily explore the selected list of actions and incorporate them into their planning processes. By doing so, the Handbook aims to inform the integration of climate-resilient strategies into sector-specific policies, ensuring sustainability both in the short and long term, in alignment with global climate objectives. Table 1 presents the actions selected for the Agriculture domain, described in terms of a sub-set of criteria, including: i) Strategy, i.e. hard/ soft options; ii) Purpose, i.e. adaptation/ mitigation; iii) IPCC macro-categories; iv) IPCC categories; v) Type of option; vi) Climate Alteration impacts considered; vii) Climate alteration drivers considered.

Among the options selected for the Agriculture domain, Biological Nitrogen fixation (BNF) is identified as a significant option, based on its positive outcomes in terms of reduction of CO 2 equivalent emissions, adaptation and socio-economic co-benefits, modest cost and reduced time of implementation [18, 20].

Nitrogen fixing crops form symbiotic interactions with bacteria in the soil enabling Nitrogen fixation and N utilisation to produce a competitive advantage when N is limiting. Selected crops (legumes) can fix over 300 kg N/ha/y providing a Nitrogen input comparable with N fertilizer applications. Legumes also provide N to subsequent crops, are a useful intermediate crop in arable rotations and provide potential biodiversity benefits [61].This mitigation action is considered with respect to its potential for reducing emissions of N_2O, via decreased utilization of N fertilizers. The action can be implemented by cultivating a greater proportion of N fixing crops in a rotation or including more legumes (e.g. clover species) in pasture. BNF is categorized as a soft measure relevant to adaptation and mitigation objectives. It is also considered as a structural, ecosystem-based solution, based on green options. Drivers and impacts of climate alteration considered include Nitrogen emissions and precipitation decrease and aridity. As a result, potential positive outcomes in terms of mitigation refer to reduced N_2O Emissions. In terms of adaptation, BNF can result in Reduced nitrate loss, improved water quality, Preserving Biodiversity, Improved structural diversity of farmland landscapes, and Improved soil fertility. Socio-economic co-benefits include Increased yield, Reduced utilization of fertilizers, Reduced Costs and Increased Gross Margin. Relevant indicators include Carbon Sequestered (C-SEQ), for evaluating mitigation benefits, Implementation Cost (IC), and

Table 1. Actions selected for the Agriculture Domain

Agriculture (AG)							
Measure	Denomination	Purpose	Macro-category	Category	Principal Type of Action	Climate Change Drivers	Climate Change Impacts
1	Conversion of arable land to grassland	Adaptation/ Mitigation	Structural and Physical; Social	Ecosystem based/ Behavioural	Green Options/ Modification of Practices	Carbon Emission;	Soil Erosion
						Nitrate loss;	
2	Minimum soil disturbance	Adaptation/ Mitigation	Social;	Behavioural;	Modification of Practices	Carbon Emission;	Soil Erosion
			Structural and Physical	Ecosystem based/ Technological			
3	Agroforestry	Adaptation/ Mitigation	Social; Structural and Physical	Behavioural;	Green options, Capacity building and Modification of practices		Deficient Precipitation;
				Ecosystem-based			Extreme Temperatures;
							Flooding
4	Afforestation and Reforestation	Adaptation/ Mitigation	Institutional; Structural and Physical	Government policies and programmes; Ecosystem-based	Management and planning, Green options		Deficient Precipitation;
							Extreme Temperatures;
							Flooding
5	Biological N fixation	Adaptation/ Mitigation	Structural and Physical	Technological/ Ecosystem-based	Green options	N20 Emissions (D)	Deficient Precipitation
							Water Scarcity
6	Leaving crop residues on the soil surface	Adaptation/ Mitigation	Structural and Physical	Technological/ Ecosystem-based	Green options		Deficient Precipitation
							Increased Temperature

(*continued*)

Table 1. (*continued*)

Agriculture (AG)							
Measure	Denomination	Purpose	Macro-category	Category	Principal Type of Action	Climate Change Drivers	Climate Change Impacts
7	Nutrient Management	Mitigation	Social	Behavioural	Cropping practices, patterns, and planting dates	N2O Emissions (D);	Storms;
							Floods;
							Increased Temperature;
8	Cover/ Catch Crops	Adaptation/ Mitigation	Structural and Physical and physical	Technological/ Ecosystem-based	Green options	Carbon Emission;	Floods
						N2O Emission	Soil Erosion, Salinization, Desrtification

Cropland Surface Area (CSA) for evaluating the quantity of the domain component targeted by the option given a cost factor and budget constraints. The estimated time of implementation is 1 year. The option is implemented at a local level, and Regional institutions are responsible for developing plans, regulations and financial instruments for incentivising the action implementation. More precisely, relevant financial instruments consist of forms of compensation including incentives and subsidies. Lastly, the resulting cost-benefit balance is positive and the potential of maladaptation is marginal.

5 Conclusions

This study proposes a structured and replicable taxonomy of climate change mitigation and adaptation actions, aimed at supporting the design of effective regional strategies, with a specific focus on the Basilicata Region in Southern Italy. Developed within the framework of the GD-CURE project, the research embraces a multi-scalar and integrative approach to territorial governance, translating global and national climate policy frameworks into actionable local tools [62, 63].

The proposed list of actions was developed through a four-step methodology—ranging from the identification of relevant domains to the comparative assessment of selected actions—and is structured around evaluation criteria and relevant descriptive elements. This framework allows for the systematic assessment and selection of actions based on their relevance, feasibility, and adequacy, ensuring alignment with the most recent scientific evidence and strategic directives. The resulting handbook serves as a decision-support tool that facilitates the evaluation, comparison, and spatialization of climate actions across various intervention domains. It is designed to support stakeholders and policy-makers in co-designing context-specific strategies for Basilicata Region in the sector of Climate Adaptation Planning [64, 65].

The handbook and its integration within geo-design workshops [66–68] further enhance the practical utility of the research. Moreover, the approach is transferable to other regional contexts, offering a flexible and coherent Decision Support System (DSS) aligned with the goals of the European broader green transition. It contributes to the advancement of climate-resilient, integrated, and sustainability-oriented planning strategies especially at regional governance scale [69, 70].

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