Targeting adaptation to safeguard sustainable development against climate-change impacts

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Targeting adaptation to safeguard sustainable development against climate-change impacts

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Abstract

The international community has committed to achieve 17 Sustainable Development Goals (SDGs) by 2030 *and* to enhance climate action under the Paris Agreement. Yet achievement of the SDGs is already threatened by climate-change impacts. Here we show that further adaptation this decade is urgently required to safeguard 68% of SDG targets against acute and chronic threats from climate change. We analyse *how* the relationship between SDG targets and climate-change impacts is mediated by ecosystems and socio-economic sectors, which provides a framework for targeting adaptation. Adaptation of wetlands, rivers, cropland, construction, water, electricity and housing in the most vulnerable countries should be a global priority to safeguard sustainable development by 2030. We have applied our systems framework at the national scale in Saint Lucia and Ghana, which is helping to align National Adaptation Plans with the SDGs, thus ensuring that adaptation is contributing to, rather than detracting from, sustainable development.

Main

In 2015, governments committed to achieve 17 Sustainable Development Goals (SDGs) with 169 related targets *and* to enhance climate mitigation and adaptation under the global Paris Agreement. Despite calls for aligning SDG and climate efforts[1], governments continue to operationalise their SDG and climate commitments in siloes. For example, while UN guidelines state the need to integrate SDG objectives in National Adaptation Plans (NAPs)[2], to date only four of twenty NAPs mention SDG targets and only two refer to SDG-aligned indicators (Supplementary Table 1).

Aligning SDG and climate commitments is critical because recent research indicated that 72 of the 169 SDG targets (43%) can be directly undermined by climate-change impacts, and that climate action under the Paris Agreement can reinforce or hamper 134 targets (79%) across all SDGs[3]. Nevertheless, research to date has not systematically documented *how* SDG targets are affected by climate-change impacts. Without a holistic understanding of the relationship between SDG targets and climate-change impacts, it is not possible to target action to align SDG and climate commitments[4].

Closing this research gap requires identifying an intermediary between SDG targets and climate-change impacts that provides a direct entry-point into more granular and spatially-explicit decision-making[5–7]. Ecosystems and socio-economic sectors can provide such an intermediary, as these are critical both for the SDGs and for climate action. Previous research has highlighted the role of ecosystems and socio-economic sectors for achieving SDG targets[8–14], which has been used to inform SDG decision-making in practice[15]. Past research has also estimated risks from climate change on ecosystems and socio-economic sectors[16–22], which has informed spatially-explicit climate action. Studies that integrate SDGs and climate-change impacts in the context of ecosystems and socio-economic sectors has so far focused on climate *mitigation*[20]. However, no such integration exists in the context of climate *adaptation*.

Yet, adaptation (the process of managing risks from climate change[23]) across ecosystems and socio-economic sectors is critical to achieve both the SDGs by 2030[3] and the Paris Agreement. Societies that fail to protect and/or adapt their ecosystems and socio-economic sectors will experience growing climate-change impacts. These manifest through acute impacts (such as damaging cyclones or extreme precipitation), which inhibit SDG progress at a specific point in time; and chronic climate-change impacts (such as ocean acidification or annual precipitation changes), which progressively affect SDG progress[16] (Figure 1, lower curves). Action on adaptation can help societies break out of this trap of increased climate-change impacts and depleted development, thereby closing their adaptation gap[24] and shifting them onto the upper trajectory of climate-resilient development (Figure 1, upper curve).

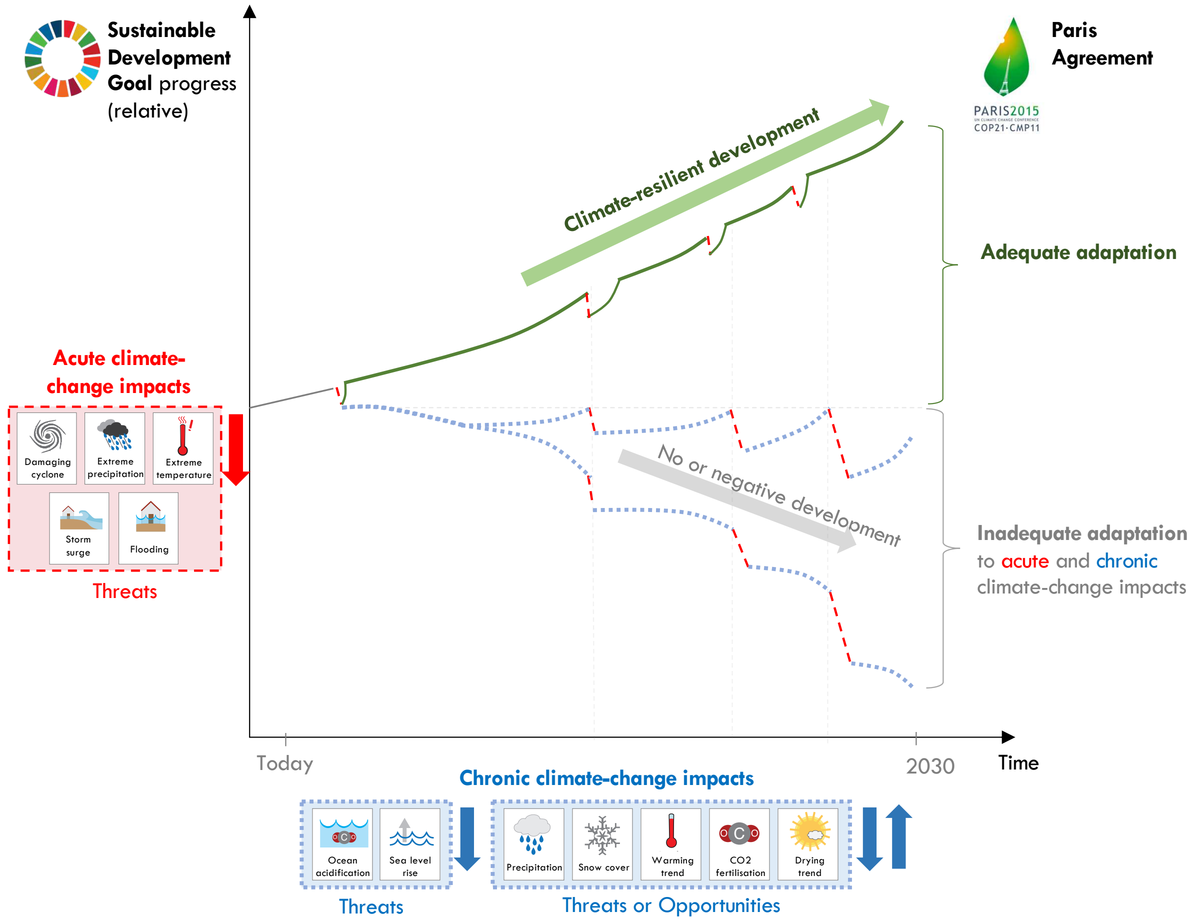


Figure 1: Action on adaptation (green bold lines) safeguards achievement of the Paris Agreement and the Sustainable Development Goals (SDGs) in the 2030 timeline. Inaction on adaptation to acute climate-change impacts (damaging cyclones or flooding) can threaten progress of the global agreements at one point in time (red dashed lines), whilst inaction on adaptation to chronic climate-change impacts (ocean acidification or dying trend) can materialise as threats or opportunities to progress on the global agreements (blue dashed lines). List of climate-change impacts is adopted from the IPCC[16].

In this paper, we propose and apply a systems framework that enables decision-makers to target adaptation towards achieving the upper trajectory of climate-resilient development (see Extended Data Figure 1 and Methods). Central to our framework is a systematic analysis of land-uses across ecosystems and socio-economic sectors, which provide services that are necessary for the SDGs and for mediating climate-change impacts. Natural or semi-natural ecosystems are classified into grasslands, savannas & shrublands, forests, rivers & lakes, wetlands & peatlands, barren, polar/alpine, and croplands. Depending on their context, these ecosystems can provide the following services: regulating (flood protection or carbon sequestration), provisioning (food, water, transport, energy or medicines), supporting (habitat), and cultural services (heritage, recreational)[8,25]. Socio-economic sectors and their services are sub-classified into three categories*:* *utilities* (electricity, transport, water), *primary/secondary* (manufacturing, mining, construction) and *tertiary* (public administration, education, healthcare, amongst others) (see Supplementary Tab 1 and 2.1). Taking a service-centric approach, our systems framework is based on two phases, analysing how:

i) each of the SDG targets can be influenced by ecosystems and socio-economic sectors;

ii) each of these ecosystems and socio-economic sectors can be affected by acute and chronic climate-change impacts (see Supplementary Information Tab 3.1 and 3.2 for evidence).

We integrate i) and ii) to derive *how* SDG targets are affected by, and can be safeguarded against, climate-change impacts. Our findings fill a critical gap, because we identify that adapted ecosystems can safeguard 105 of all 169 SDG targets (62%); adapted utility infrastructure can safeguard 121 targets (72%); adapted primary/secondary sectors can safeguard 67 targets (40%); and adapted tertiary sectors can safeguard all SDG targets.

We then apply our systems framework to quantify how *near-term risk* from acute and chronic climate-change impacts can threaten SDG targets. *Near-term risk* is here defined based on the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5)[16] as a function of high probability/large magnitude hazard, persistent exposure and vulnerability by the 2030s (aligned with the SDG timeline). Finally, we demonstrate how our systems framework is applicable at the national scale to align SDG targets with commitments under the Paris Agreement.

SDG targets influenced by ecosystems and socio-economic sectors

In the first phase, we identify how each SDG target is influenced by ecosystems and socio-economic sectors, differentiating by *direct, interdependent,* and *indirect* influences.

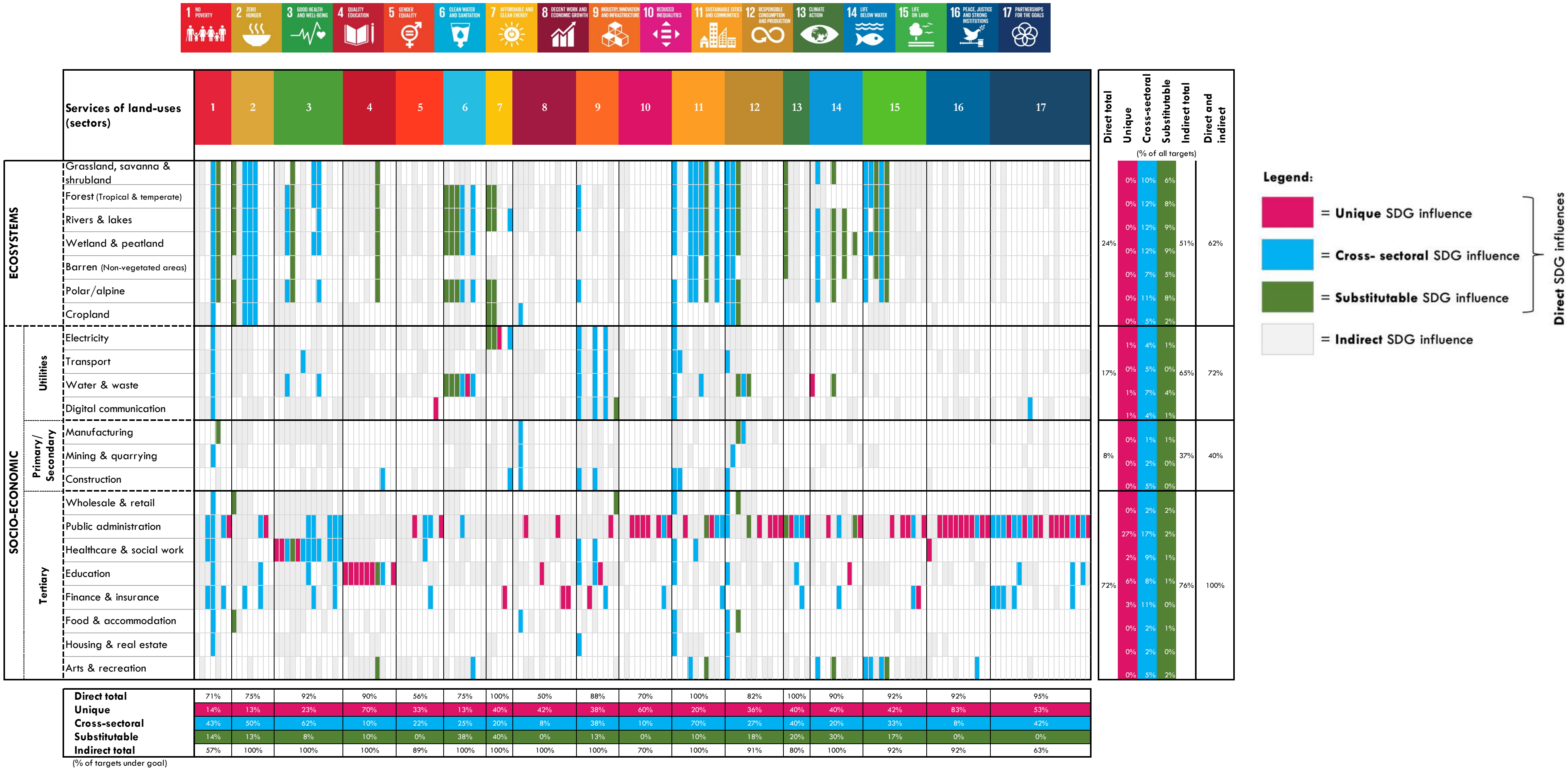
We define *direct* SDG influences as cases where SDG targets are described in terms of a sector's service, in line with previous research[11] (see Methods). Collectively, we find that 141 of all 169 SDG targets (83%) are *directly* influenced by ecosystems and socio-economic sectors, i.e. these targets are directly described in terms of these sectors' services. With respect to ecosystems, 40 SDG targets (24%) are *directly* influenced by ecosystem services (Figure 2, coloured shading). In addition to targets under SDG14 ('life below water') and SDG15 ('life on land') that explicitly mention ecosystems[14], we find that targets under 12 different SDGs are directly influenced by the regulating, provisioning, supporting, and cultural services that ecosystems provide.

With respect to socio-economic sectors, 29 SDG targets (17%) are *directly* influenced by infrastructure services provided by utility sectors, such as electricity or transportation services; 13 targets (8%) are *directly* influenced by services provided by primary/secondary sectors, including manufacturing or construction services; and 122 targets (72%) are directly influenced by services provided by tertiary sectors, such as public administration or healthcare services.

We distinguish ecosystems or socio-economic sectors (hereafter referred to as sectors) for practical reasons, acknowledging that multiple sectors act *interdependently* to provide services. For example, water services can be provided by both rivers and physical utilities; ecosystem services such as flood protection can complement or substitute physical infrastructure services; and socio-economic governance services enable equitable ecosystems management. Additionally, cultural services permeate through and across all sectors[26]. We consider *interdependencies* in direct SDG influences by accounting for whether SDG target progress requires *unique*, *cross-sectoral*, or *substitutable* contributions. Whilst some SDG targets are described in terms of a single sector's service only (*unique* influence), other targets are described in terms of multiple sectors' services (*cross-sectoral* influence) or in terms of a sector's service that can be substituted by a different sector (*substitutable* influence).

We find that 68 SDG targets (40%) are influenced *uniquely* by a single sector's service (Figure 2, magenta shading), where targets under SDG16 ('peace') require most unique influences. In contrast, 53 targets (31%) are influenced by multiple services from different sectors, where each sector provides a *cross-sectoral* influence to SDG target progress (Figure 2, blue shading). Targets under SDG11 ('sustainable cities') require most cross-sectoral influences. In addition, 20 targets (12%) are influenced by a sector's service that is *substitutable* by another sector (Figure 2, green shading). Targets under SDG7 ('energy') are influenced by most substitutable sector contributions.

SDG target progress can also be *indirectly* influenced by services from ecosystems and socio-economic sectors. *Indirect* SDG influences are defined as cases whereby a sector's service is not directly mentioned in the target's description but for which published evidence indicates SDG target links. For example, there is evidence of the job creation benefits of ecosystem restoration in relation to SDG8 ('decent work')[27]. We identify on average four times more indirect SDG influences than direct ones (Figure 2, grey shading). The ratio of indirect-to-direct SDG influences is largest for sectors of the primary/secondary category due to their role in facilitating the provision of other sectors' services. For example, SDG7.2 ('increasing the share of renewables') is indirectly influenced by lithium mining, which is critical to manufacture batteries that contribute to renewable energy systems[28]. Comparing across goals, SDG8 ('decent work') and SDG5 ('gender equality') are influenced by eight and six times more indirect sector contributions relative to direct ones, respectively.

148 

149 *Figure 2:* ***SDG targets influenced by ecosystems and socio-economic sectors.*** *Each rectangle represents one SDG target; magenta shading denotes a unique direct influence; blue*
150 *represents a cross-sectoral direct influence; and green denotes a substitutable direct influence for achieving the SDG target. Grey indicates an indirect influence, where there is published evidence that*
151 *improving the quality/quantity of the sector's services can help achieve the SDG target. White shading indicates the absence of identified evidence. Evidence is reported in Supplementary Information*
152 *Tab 3.1.*

Ecosystems and socio-economic sectors influenced by climate-change impacts

In the second phase, we identify how the quantity and/or quality of sectors' services can be threatened by acute and chronic climate-change impacts (Figure 3, red and blue shading). Comparing the expected change in hazard frequency across all acute climate-change impacts under a 1.5°C and 2°C warming scenario, we find the largest increase for extreme temperatures (Figure 3, percentages and arrows). Based on IPCC AR5 classification of highest global *near-term risk*[16], the provision of services from six sectors is at high near-term risk from extreme temperatures (Figure 3, exclamation marks). This includes the provision of water, food, electricity, construction and housing services, which is likely to have most devastating consequences for sectors or populations with highest vulnerability. Vulnerability is here defined as sector's sensitivity to climate-change impacts and/or society's adaptive capacity (a function of a population's socio-demographic status[29,30]). Sectors where service provision is already poor, declining, or endangered from other stressors are likely to be more vulnerable to additional climate-change impacts. Similarly, poorer societies are less capable to recover from climate-induced losses by means of diversification of incomes, amongst other factors.

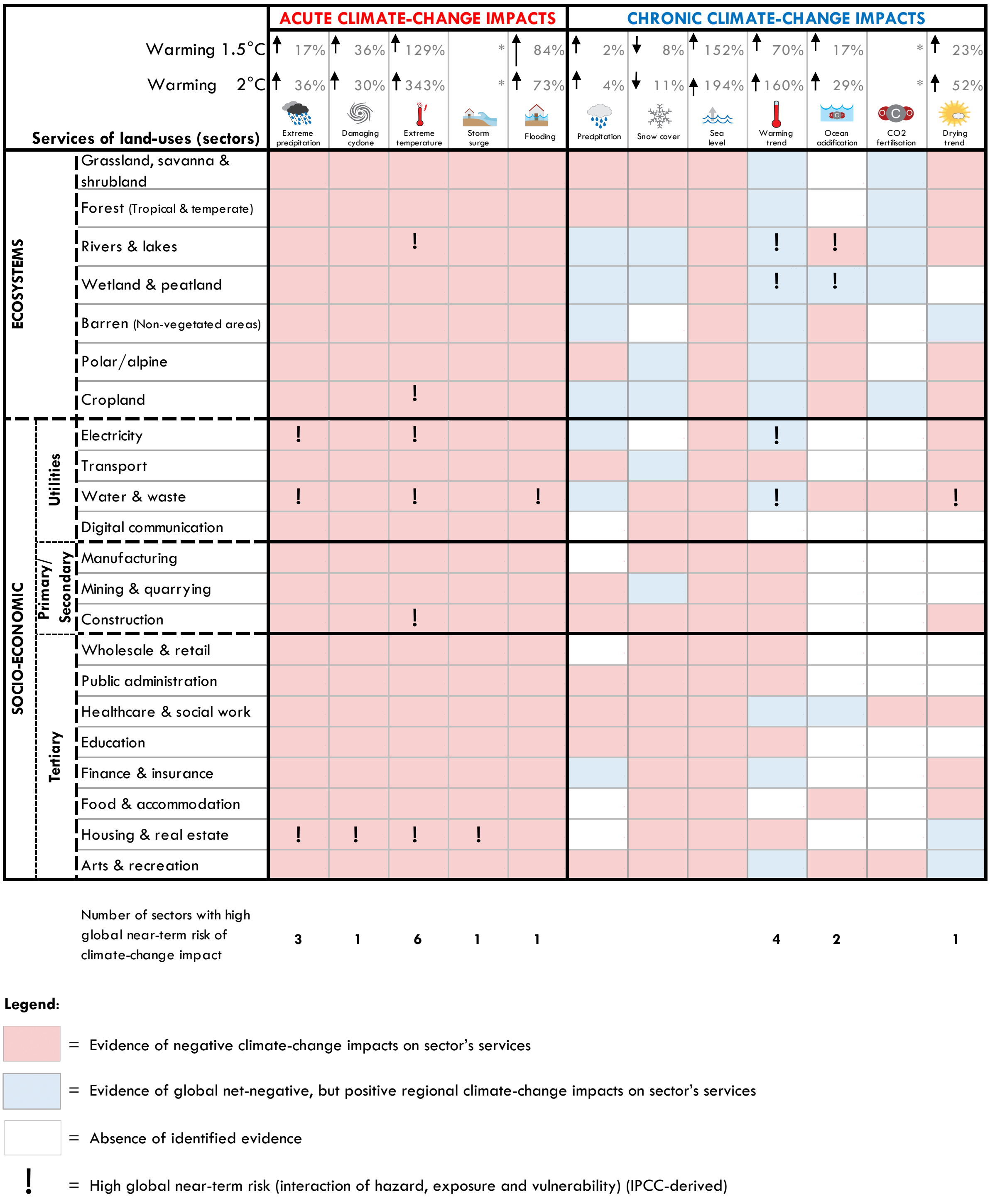


Figure 3: ***Ecosystems and socio-economic sectors influenced by acute and chronic climate-change impacts.*** *Red shading denotes evidence of a negative impact, blue shading highlights a global net-negative impact, but potential positive regional effect of climate-change impact on services. White shading indicates the absence of identified evidence. Evidence is reported in Supplementary Information Tab 3.2. Exclamation marks represents high near-term risk based on IPCC AR5 TS.4*[16]*. Percentages for climate-change impacts signify changes in frequency under a 1.5 and 2°C scenario (see Supplementary Table 2 and Supplementary Information Tab 3.3), whereby the symbol * suggests that no quantified evidence was identified.*

Chronic climate-change impacts predominantly influence ecosystems and socio-economic sectors negatively, with some regional positive effects. For example, chronic warming is projected to reduce agricultural yields globally, but may increase yields in northeast China and the UK[31]. Evidence shows that limiting warming to 1.5°C can substantially reduce the frequency of all chronic climate-change impacts, especially for precipitation, chronic warming, and the drying trend (Figure 3, percentages). Yet, even at 1.5°C, the provision of services from four sectors remains at high global near-term risk from chronic warming (Figure 3, exclamation marks). This includes the provision of essential ecosystem, water, and electricity services. Combining acute and chronic findings under the 1.5°C scenario, we identify that seven sectors are at high global near-term risk from extreme temperatures and chronic warming. These seven at-risk sectors include rivers & lakes, wetland & peatland ecosystems, croplands, the electricity, water & waste, construction, and housing & real estate sector.

SDG targets influenced by climate-change impacts

We derive our systems framework by integrating (i) how SDGs are influenced by ecosystems and socio-economic sectors and (ii) how these sectors may be impacted by climate-change impacts. This allows us to identify that progress for 141 of 169 SDG targets (83%) can be *directly* undermined by all acute climate-change impacts via all considered sectors (Figure 4). Chronic climate-change impacts, which have either negative or regionally positive effects, can threaten 37% more SDG targets than they can support through opportunities. When combining *direct* and *indirect* influences, we find that progress for all SDG targets can be affected by acute and/or chronic climate-change impacts on sectors' services.

Applying this systems framework globally, we identify that the seven sectors at high near-term risk from extreme temperatures and chronic warming can *directly* influence 36% of SDG targets (Figure 4, exclamation marks). Especially affected are SDG6 ('clean water'), SDG7 ('energy'), SDG9 ('innovation and infrastructure'), SDG11 ('sustainable cities') and SDG12 ('responsible consumption and production') where more than 50% of each goal's targets are influenced by the seven sectors. When considering both *direct and indirect* effects, we find that high near-term risk can affect 68% of SDG targets across all 17 goals.

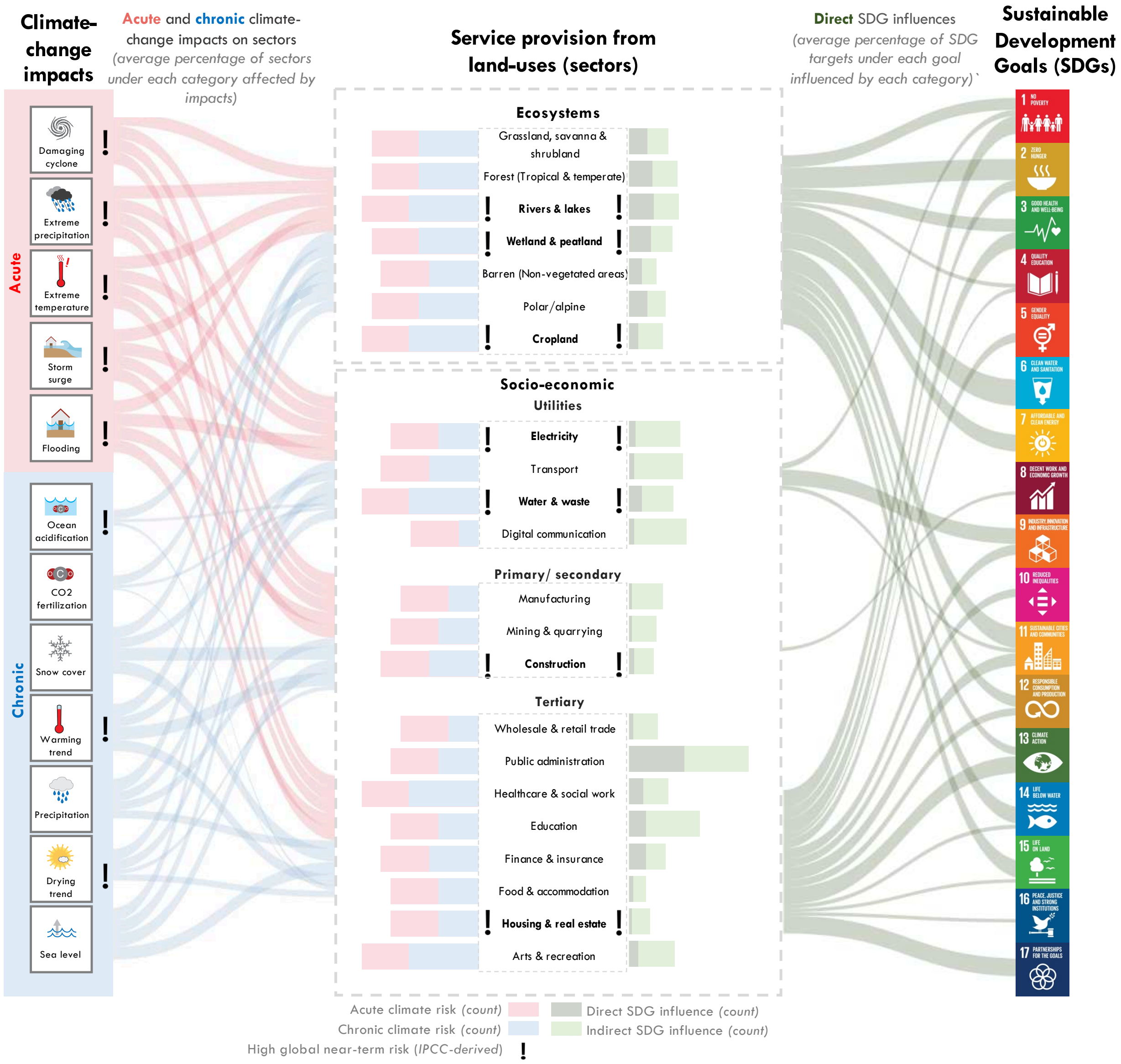


*Figure 4: **Systems framework**, showing (from left to right): Percentage of sectors under each category (ecosystems, utilities, primary/secondary, tertiary) impacted by acute (red Sankey lines) and chronic climate-change impacts (blue Sankey lines); quantity of acute (red bars) and chronic climate-change impacts (blue bars) on sectors; quantity of direct (dark green bars) and indirect SDG target influences (light green bars) from sectors; and the percentage of SDG targets under each goal directly influenced (green Sankey lines) by each sector category. Exclamation marks (left) denote high global near-term risk[16].*

Tailoring adaptation to safeguard SDG progress

We show how our systems framework can be used to tailor adaptation, which we then discuss in the context of our global near-term risk findings.

In tailoring adaptation to SDG targets, we focus on how sectors influence targets (*unique, cross-sectoral, substitutable, indirect*). Where SDG targets are directly influenced by a single climate-sensitive sector, adaptation can focus *uniquely* on that sector. We find that adaptation of public administration, which includes implementing just policy, can uniquely safeguard most SDG targets (27%).

Where SDG targets are influenced by different climate-sensitive sectors, *cross-sectoral* adaptation is needed. Adapting the public administration, finance & insurance, and forest sector can safeguard most SDG targets through cross-sectoral contributions (17%, 11% and 11% of SDG targets, respectively) where each service provides an independent contribution to target achievement.

In cases where SDG targets are influenced by climate-sensitive sectors that provide *substitutable* functions, decision-makers can choose where to adapt. We find that protecting or enhancing ecosystem services – including rivers & lakes, forest, and wetlands & peatlands – can safeguard 10%, 8%, and 8% of SDG targets, respectively, through substituting socio-economic sectors.

Awareness of indirect SDG influences is critical for decision-makers to maximise co-benefits of adaptation. Given our finding that SDG8 and SDG5 are influenced by most indirect influences (eight and six, respectively) compared to direct ones, embedding local economic opportunities and gender considerations across all adaptation policies can maximise SDG contributions.

In tailoring adaptation to reduce risk, we differentiate by the three components of risk: *hazard*, *exposure*, and *vulnerability*. Firstly, decision-makers might focus adaptation on areas projected to experience proportionally more frequent/severe *hazards*. Adaptation options could include greening to reduce extreme temperatures in cities or restoring wetlands to reduce flood severity.

Secondly, decision-makers might tailor adaptation based on how hazards *expose* sector's supply ('land/resources', 'physical capital', 'labour') or demand (Supplementary Information Tab 3.2). For example, on agricultural croplands there is evidence that extreme temperatures mainly expose outdoor-working agricultural 'labour', whilst floods mainly affect agricultural 'physical capital' (Figure 5, horizontal sector comparison). Therefore, whilst working hour policies might reduce exposure on 'labour', better flood protection is needed to reduce exposure on 'physical capital'.

Thirdly, decision-makers may tailor adaptation based on which sectors/populations are more *vulnerable* to hazard exposure. For example, already threatened ecosystems/species are more sensitive to hazards, and poor agricultural workers who are already working under insecure arrangements are less capable to adapt[16]. Vulnerability-based adaptation may therefore focus on integrating biodiverse habitats to connected networks to enable threatened plant/animal species to adapt in response to climate change[32], or on social protection policies to increase adaptive capacity.

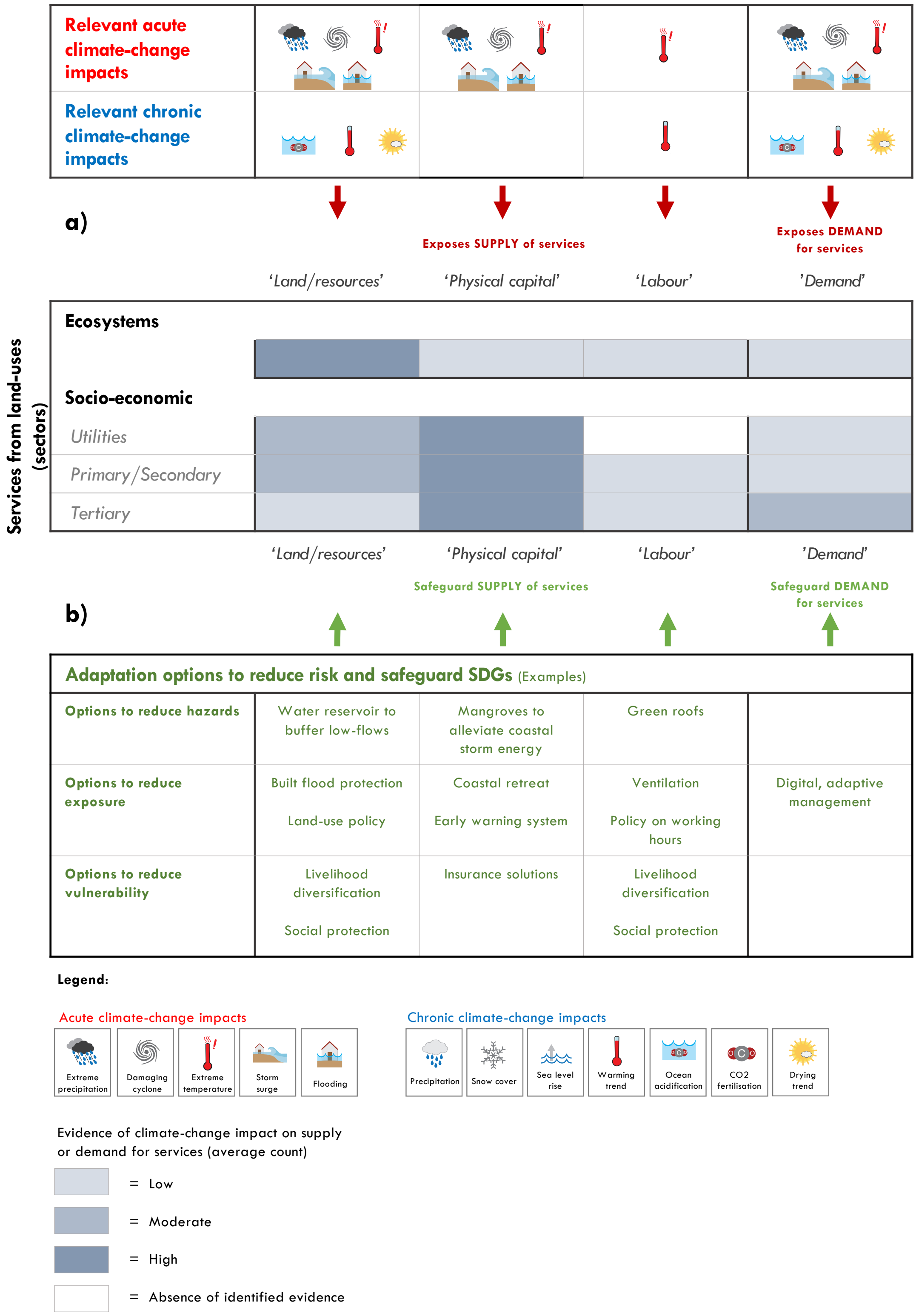


Figure 5: ***Tailoring adaptation to climate-change impacts.*** *Example adaptation options applicable to acute and chronic climate-change impacts, based on average count of evidence on how climate-change impacts affect ecosystems and socio-economic sectors. Absence of colour indicates the absence of identified evidence. a) Effects of acute and chronic climate-change impacts on supply of and demand for services of different sector categories; b) Ability of adaptation options to safeguard service provision in the face of climate-change impacts. The example list of adaptation options is not extensive.*

In light of our global near-term risk findings, we identify that safeguarding those targets influenced by multiple climate-sensitive sectors (especially under SDG9, SDG11 and SDG12) necessitates *cross-sectoral* adaptation across the seven at-risk sectors. Where possible, adaptation options should be designed to both reduce risk and to maximise additional SDG contributions, as can be the case with nature-based solutions. If they respect cultural and ecological rights and support biodiversity[33], nature-based solutions (e.g. urban greening) can provide a valuable adaptation option to safeguard multiple climate-sensitive sectors against extreme temperatures (*hazards)* whilst providing cultural and regulating services that underpin SDGs. Sector-specific adaptation policies on improved land-use planning can reduce *exposure* of agricultural or cropland workers whilst minimising land-use trade-offs[34]. Upgrading informal settlements can reduce population's *vulnerability* to extreme events whilst building socio-economic resilience[16].

To globally safeguard the near-term climate-sensitive targets under SDG6 and SDG7 with many *substitutable* influences, decision-makers have a choice on where to focus adaptation. For example, achievement of SDG6 could be safeguarded by prioritising protected river & lake or wetland & peatland ecosystems less affected by chronic warming to substitute for, or complement, climate-sensitive dams. Such substitution should be targeted maximise SDG contributions, for example through community-based natural resource management[35] which builds both social capital and adaptive capacity.

Some near-term climate-sensitive SDG targets, especially under SDG11, are influenced by at-risk sectors that provide globally *non-substitutable* services in safeguarding wellbeing[36]. For example, rivers & lakes and wetland & peatland ecosystems provide regulating air purification as well as natural and cultural heritage services that are globally non-substitutable. These regulating and cultural services are already threatened by other stressors, evidenced by the declining contribution of ecosystem regulating and cultural services to the SDGs over time[37]. Therefore, unless these highly productive and non-substitutable ecosystems are urgently protected against near-term risk, it will not be possible to safeguard the SDG targets they influence.

A national adaptation roadmap for climate-resilient development

Beyond global application of near-term risk, we have also used our systems framework nationally, including in Ghana and Saint Lucia[38]. In Ghana, analysis identified the north-east district as a priority for adaptation in the provision of energy to safeguard SDG7, which is feeding into the revision of Ghana's Nationally Determined Contributions (NDCs). Resilient renewable energy investments in this area can have indirect benefits for SDG5 and SDG13, given that women spend most time collecting hazard-prone firewood and because of the low adaptive capacity of the district's population.

In Saint Lucia, we standardised and geo-referenced data across 24 sectors and 13 ministries together with the Government of Saint Lucia and its 'National Integrated Planning and Programme Unit' in order to assess how and where adaptation can safeguard SDG achievement. This assessment revealed priority adaptation options such as conserving Saint Lucia's pristine wetland which provides both flood protection services to the only road connecting the north and the south of the island as well as important ecosystem services, contributing to a total of 115 SDG targets. This application allowed accounting for SDG targets in Saint Lucia's NAP (Extended Data Figure 2), which remains an unmet requirement for most NAPs. In pinpointing areas, assets or populations at high risk of climate-change impacts in the context of the SDGs, these national applications provided evidence, at high spatial granularity, of how and where to prioritise adaptation in the context of the SDGs, thereby informing NAPs and NDC revisions.

As more nations around the globe revise their SDG and climate commitments, including in relation to covid-19 recovery packages, we propose a six-step national adaptation roadmap. The roadmap is centered around an iterative stakeholder-led process and a multifunctional landscape approach[39] that consider interdependencies and trade-offs between ecosystems, socio-economic sectors, and the needs of different beneficiaries. It includes the following steps:

(1) identify current and desired levels of ecosystem and socio-economic service provision in relation to needs and SDG-aligned targets[15] across spatially vulnerable populations (e.g. using citizen-science data[40]);

(2) combine top-down and bottom-up climate assessments[4] (e.g. spatial risk analyses[41], statistical methods[42], or mixed methods) to assess how current and desired future service provision is at-risk from climate-change impacts, using unified metrices where possible;

(3) prioritise adaptation needs across sector, areas, and hazards, considering interdependencies;

(4) co-produce adaptation options with local and indigenous peoples, assess trade-offs[43], and consider issues of equity, fairness and justice[20];

(5) systematically evaluate adaptation to test the reliability, effectiveness and potential maladaptation consequences[44] of nature-based solutions alongside traditional engineering options[45], and to identify low-regret adaptation options;

(6) develop dynamic adaptation plans aligned with the SDGs and grounded in living data systems, that help transcend siloed practices across public, private, civic and academic spheres[46,47].

This adaptation roadmap is applicable to all nations, irrespective of their development status. For high-income nations where socio-economic service needs are mainly met, the roadmap can inform where to target adaptation under NDC commitments based on highest risk and largest SDG contribution, ensuring that *climate adaptation is sustainable*. For lower-income nations characterised by inadequate basic service provision, the roadmap can help ensure that *development is climate-resilient*. This includes working with nature and indigenous peoples to safeguard threatened ecosystems whilst deploying the vast amounts of SDG investments forecasted to meet needs in a way that reduces future climate risks.

Discussion

Shaped by institutional, power, and political factors, targeting adaptation to safeguard and contribute to SDGs remains a complex and challenging task. Our proposed systems framework provides a practical starting point to navigate these complexities and is spatially-explicit and transferable across nations. Global and national applications of the framework can provide valuable insights for: (i) international organisations to better target adaptation aligned with the SDGs and the Paris Agreement as well as the Sendai Framework and the Aichi Biodiversity targets; (ii) national governments to ensure SDG are integrated in adaptation communications; and (iii) investors and the private sector to inform them about climate-change impacts on, and potential SDG contributions of, their investments and/or assets.

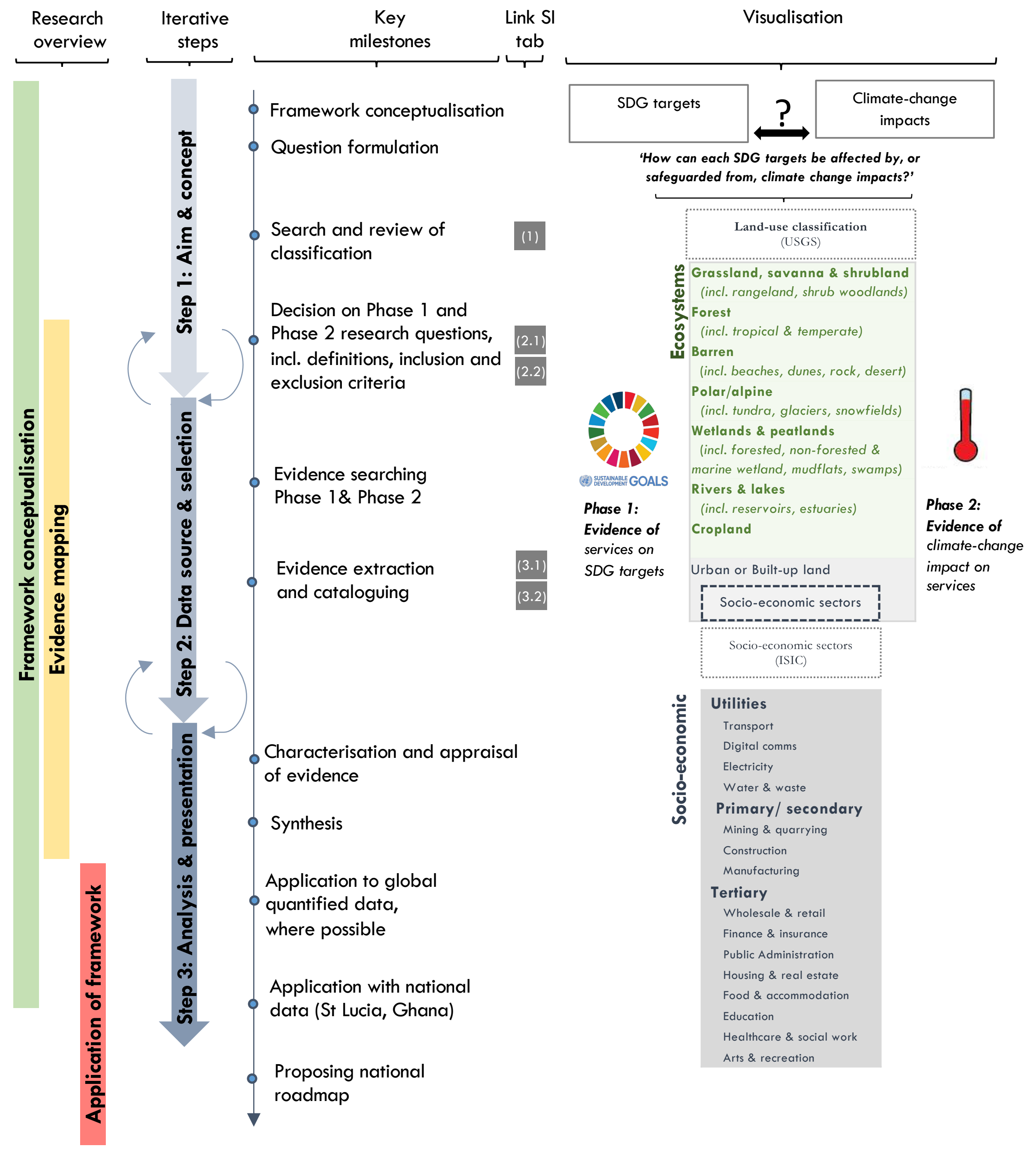
Despite climate mitigation being the focus of research and funding in the context of SDG targets[20], we find that without targeted adaptation, global efforts to achieve the SDGs by 2030 are being threatened by climate-change impacts. We demonstrate not only the scale and complexity of this threat, but also the societal value of sectoral adaptation. Whilst multi-sector adaptation can help safeguard the SDGs, it requires determination and coordination across traditional siloes.

Methods

Based on evidence mapping of influences, we propose a systems framework to identify how SDG targets may be influenced by (in)action on climate change adaptation. Our proposed framework differs from previous research that characterised evidence of: a) climate-change impacts directly on SDG targets[3], b) specific sectors on SDG targets[8–13,48], and c) interdependencies between different SDGs[49–52]. To date, these studies have made the broad case for connecting climate-change impacts and the SDGs[3], and have provided a more granular identification of how sectors can enhance SDG target progress[8–13,48]. For the first time, we integrate and expand this research to provide a granular leverage point into decision-making towards both the SDGs and reducing risks from climate-change impacts. Our proposed framework includes a holistic set of ecosystems and socio-economic sectors (representing the three pillars supporting sustainable development: environmental, social and economic[53]), considers interdependencies between sectors, and differentiates by different acute and chronic physical climate-change impacts. We apply this systems framework to high near-term risk from climate-change impacts, as defined by the IPCC Table TS.4[16] as risk resulting from the following criteria: large magnitude, high probability, or irreversibility of impacts; persistent exposure or vulnerability; limited potential to reduce risks through adaptation or mitigation. These risk levels integrate probability and consequence over the widest possible range of potential outcomes resulting from the interaction of climate-related hazards, exposure, and vulnerability, based on available evidence[16].

Research design

Our framework is based on best practices for evidence mapping processes in adaptation research as proposed by Berrang-Ford et al.[54], which includes three main steps: 1) aim and conceptualisation, 2) data source and document selection, and 3) analysis and presentation of results. The first step involved drawing the boundaries of the research, conceptualising the research, and identifying clear research questions. The second step involved describing the search process, which included searching Web of Science and Google Scholar for published evidence on how: 1) SDGs are influenced by sectors' services, differentiating by different type of influences, 2) sectors' services are influenced by climate-change impacts, differentiating by the type of impact. We have drawn on the expert elicitation process adopted in previous studies[3,11], using an iterative approach to discuss ambiguous influences, which was subsequently reviewed by the authors. The justification for the classification used, the evidence, definitions, and specific inclusion and exclusion criteria were extracted from the literature and are catalogued in Supplementary Information Tab 1 - 3.3. The third step involved characterising and appraising the evidence base through a binary process: whether or not there is an influence. It further included integrating influences between SDG targets and sectors, and sectors and climate-change impacts. These three steps were iteratively conducted with the author team and involved a set of discussion meetings (Extended Data Figure 1).



Extended Data Figure 1: Conceptualisation and application of our systems framework, based on evidence mapping of influences. SI = Supplementary Information.

Step 1: Aim & concept

The aim of this research was to identify a framework of how the SDG targets can be influenced by different climate-change impacts in order to provide a direct entry point for decision-makers to prioritise and target adaptation in the context of the SDGs. Previous literature has identified that this additional step requires a more granular analysis that can be contextualised to suit the specific needs of decision-makers at different scales (global, national, public and private sector, academic modelling), which necessitates a role for an intermediary[4]. Therefore, addressing our aim involved designing a framework to ensure relevance for decision-makers to inform adaptation, via conceptualising an intermediary between SDG targets and climate-change impacts. We identified the following set of criteria for such an intermediary:

i) action within the intermediary can influence SDG targets and the adaptation component of the Paris Agreement (as an 'operator') and is influenced by the 'stimulus' of climate-change impacts (as an 'exposure unit' or 'receptor'), following an existing framework on adaptation[55],

ii) decision-makers at different levels have leverage (using policies, subsidies or investments) to act on the intermediary in the context of SDG-aligned development plans and communications under the Paris Agreement (including NDC revisions or NAPs),

iii) mentioned in nation's sectoral development plans, NDC's, or NAPs,

iv) mappable, i.e. allows for a quantitative, GIS-based translation of the framework,

v) globally applicable, i.e. consistent with international accounting standards (such as System of Environmental Economic Accounting (SEEA)) and global modelling to allow comparison across nations.

We base our intermediary on the original land-cover/land-use classification by USGS[44], which was developed using strict criteria that spatial units are geographically exclusive and exhaustive. Given that USGS was the first classification of land-cover and land-use, a range of global ecosystem and global land cover classifications build on it. Its spatial exhaustion across the globe suggests that this classification allows for a flexible approach for further disaggregation on a national and/or regional scale. In addition, geospatial data (at 250m resolution) for the terrestrial and freshwater domain is available[56]. We updated the categories in line with the SEEA-updated USGS categories (of major ecosystem types) to classify natural/semi-natural ecosystems[56], and defined services delivered by each ecosystem where possible (Supplementary Information Tab 2.1).

We further differentiate USGS' 'built-up land' by sectors from the International Standard Industrial Classification (ISIC Rev 4[45]) of economic activities. ISIC is an internationally-used classification of socio-economic sectors, provides a systematic overview of different services provided by sectors, its sectors can be spatially translated using ArcGIS online as well as Open Street Map (OSM) data, and ISIC is consistent with international accounting standards. Our review of influences focused on the service level, because the value of a sectors' asset is determined by the goods and services it provides over its life[25]. The range of potential services provided by each ecosystem and socio-economic sector were explicitly defined, with 35 different services provided by ecosystems, and a total of 32 different services provided by the socio-economic sectors (Supplementary Information Tab 1 and 2.1). Given that the analysis was performed at the service level, we grouped ecosystems based on where they can provide the same service, acknowledging that the magnitude of different services differs within categories (e.g. tropical forests provide much larger mitigative services compared to temperature forests).

We derive our systems framework through evidence mapping in two main phases, where each phase aims to answer a set of questions based on specific definitions and inclusion and exclusion criteria:

(Phase 1) Evidence mapping: SDG targets influenced by ecosystems and socio-economic sectors, differentiating by type of influence

For each of the 169 SDG targets and each of the 22 sectors, we defined three questions *(1.1-1.3):*

(1.1) 'Can progress on the SDG target be directly influenced by the services provided by the sector?' (see *definition of direct SDG influence*)

Definition of direct SDG influence:

A direct influence is identified if the SDG target is described directly in terms of the service that a sector provides. For example, target 11.6 "By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management" is directly influenced by both the 'purification of air' services provided by forests, and the 'waste management' services provided by the water & waste sector.

(1.2) 'How many sectors can directly influence progress towards the SDG target?' (see *definition of interdependent SDG influence* below)

- If '1', classify as '*unique SDG influence'*.
- If '2' or more, 'does the service perform a substitutable function in relation to achieving the target?'
    - If 'No', classify as '*cross-sectoral SDG influence'*.
    - If 'Yes', classify as '*substitutable SDG influence'*.

Definition of interdependent SDG influence (direct SDG influences only):

Unique SDG influence. A unique influence is identified when a sector's service provides independent, singular contributions towards achievement of an SDG target. For example, target 16.3 "Promote the rule of law at the national and international levels" is uniquely influenced by (i.e. directly described in terms of only) the 'law enforcement' services provided by the public administration sector. This function cannot be substituted by the services of another sector.

Cross-sectoral SDG influence. A cross-sectoral influence is identified when a sector's service provides independent, cross-sectoral contributions towards achievement of an SDG target. For example, target 11.4 "Strengthen efforts to protect and safeguard the world's cultural and natural heritage" requires the 'cultural heritage' services from the arts & recreation sector as well as the 'natural heritage' services from the forest sector. The services from these sectors must both be safeguarded to ensure target achievement.

Substitutable SDG influence. A substitutable influence is identified when sectors provide a service that can be substituted by another sector. In such a case, various sectors provide the same service to achieve progress towards the SDG target, presenting decision-makers with a choice of how to safeguard target achievement in the face of acute and chronic climate-change impacts. For example, target 6.1 "achieve universal and equitable access to safe and affordable drinking water", can be achieved through the water provision services directly abstracted from mountainous rivers or via water utilities.

(1.3) 'Is there published evidence that progress on the SDG target can be indirectly influenced by the services provided by the sector?' (see *definition of indirect SDG influence* below)

Definition of indirect SDG influence

An indirect influence is identified where the SDG target is not described specifically in terms of the service that a sector provides, but for which published evidence indicates that improving the quality or quantity of the service provided by a sector can enhance the achievement of the target, following the definition of Thacker et al.[8]. For example, target 5.2 "Eliminate all forms of violence against all women and girls in the public and private spheres, including trafficking and sexual and other types of exploitation" can be indirectly influenced by the healthcare & social work sector, as there is evidence that improving the quality of healthcare services, especially drug addiction services, can reduce violence[57]. Indirect influences include cases whereby there is published evidence that improvements in environmental management, fair provision or better governance can support achievement of the target. It excludes cases of second-order interdependencies: For example, there is no indirect influence between the mining & quarrying sector and SDG target 11.1 ("Ensure access to housing") because only a second-order influence could be identified: mining & quarrying supports the provision of minerals, which are then used in construction of housing shelter.

(Phase 2) Evidence mapping: Ecosystems and socio-economic sectors influenced by climate-change impacts, differentiating by type of influence

We categorised 12 climate-change impacts, as defined by the IPCC AR5[16], into acute (extreme) and chronic (slow-onset) climate-change impacts (Supplementary Information Tab 2.2). For each of the 12 climate-change impacts and each of the sectors, we defined two questions (*2.1* and *2.2*):

(2.1) 'Can the climate-change impact negatively influence the quantity or quality of the services provided by the sector, via impacts on 'land/natural resources', 'physical capital', 'labour') or 'demand' (see *definition of climate change influence* below)

- If 'Yes', encode as '-', and include confidence of the published evidence if available.

(2.2) 'Can the climate-change impact positively influence the quantity or quality of the services provided by the sector, via impacts on 'land/natural resources', 'physical capital', 'labour') or 'demand'?' (see *definition of climate change influence* below)

- If 'Yes', encode as '+', and include confidence of the published evidence if available.

Definition of climate change influence

An influence is identified if published evidence indicates that a climate-change impact affects the quantity or quality of services from the sector via effects on the three supply factors ('land/natural resources', 'physical capital', or 'labour') or on directly quantifiable 'demand'. Thereby, our definition of climate-change influence for sectors focuses on the exposure of sectors' functioning to climate-change impacts. We refer to climate-change impacts as 'climate-related drivers of impact' summarised by the IPCC[16]. If reference is made to 'coastal infrastructure', any socio-economic is considered to be potentially affected. If the literature makes reference to 'extreme events', the definition of the IPCC[6] was used, and the following climate-change impacts were included: extreme precipitation, damaging cyclone, extreme temperature, flooding, storm surge. The definition excludes the ways in which climate change can result in economic market readjustments (e.g. increased prices due to shortage of supply following extreme impacts).

Step 2: Data source & selection

The search for scientific evidence was conducted in four different stages (in order of search): 1) Tier 1 journals, 2) IPCC assessments (including 'Global Warming of 1.5°C'[20], 'Fifth Assessment Report'[16], 'Climate Change and Land'[34]), other peer-reviewed articles, and pre-prints, and 3) 'Grey literature' (reports from international organisations, national and subnational agencies). The search for evidence was performed through Web of Science and Google Scholar, which were chosen given their high speed of inclusion of related articles and the inclusion of preprints. A google search was used to identify evidence from stage 3 ('Grey literature'). English was used for the evidence search, as it is the most employed language and considered as the international academic language[58].

Results were filtered by date and only the most recent publication was included in the evidence mapping, given that there might be many different publications for each influence (Supplementary Information Tab 3.1 and 3.2). We did not conduct a meta review of the evidence to characterise the quality of the evidence, but hope to mitigate this aspect through our prioritised search in different stages and using the most recent available evidence.

The evidence for each influence was screened against the predetermined definitions, incl. inclusion and exclusion criteria, firstly by two of the authors. The influences were then reviewed and enriched by other authors. Finally, ambiguous influences were discussed, and inclusion and exclusion criteria refined through facilitated discussion until a consensus was reached.

Step 3: Analysis & presentation

The evidence was characterised through a binary process: whether or not there is an influence. For the SDG influences, we described the evidence in terms of absolute numbers and percentages of SDG targets potentially influenced. We categorised sectors into the following categories to provide useful implications for decision-making: ecosystems; economic sectors (primary/secondary, utility) and social sectors (tertiary). We analysed results at the service level to identify where the same service can be derived from different ecosystems or socio-economic sectors. We did not assess the magnitude of service contributions to each target, because such information is not available at the global scale across all ecosystems and socio-economic sectors, and is highly context-specific. For the climate influences, we identified whether there is a negative or positive influence from climate-change impacts on a supply factor ('land/natural resources', 'physical capital', 'labour') or 'demand' for each sector.

Finally, we combined the SDG influences (Phase 1) and the climate influences (Phase 2) in order to compute how each SDG target can be affected by climate-change impacts via sectors' services. For example, if there is published evidence of a negative effect of chronic warming on agricultural food production, we compute the number of SDG targets directly and indirectly influenced by cropland-based food production.

We further apply findings from (Phase 1) and (Phase 2) and near-term risk to discuss potential adaptation options tailored to SDG targets and to different climate-change impacts. We classified adaptation to reduce risk based on the three factors that make up risk as defined by the IPCC[59]. These include risk as resulting from the interaction of the: a) climate-change hazard – the probability and severity of a climate-change impact event; b) exposure - the land or resources, physical capital, workers or demand for a sector's services subject to a climate-change impact; and c) vulnerability – the sensitivity of a sector to impacts and the capacity of a population/ society to deal with a hazardous impact[29]. Our focus lies on planned rather than autonomous adaptation, and anticipatory rather than reactive adaptation.

To inform adaptation (Figure 5), we counted the number of climate-change impacts affecting each supply factor ('land/natural resources', 'physical capital', 'labour') or 'demand' for each sector based on available evidence on how the climate-change impact affects each sector. We averaged this count per category (ecosystem, utilities, primary/secondary, tertiary) and used an equal interval rank for each category and each supply and demand factor based on the count of climate-change impacts into 'low' (less than 4 impacts), 'moderate' (less than 8 impacts); 'high' (more than 8 of the 12 potential climate-change impacts affecting the supply or demand factor for each category).

For our global application, we compute the SDG targets that can be affected by, and require safeguarding from, high near-term risk from climate change. To identify global near-term risk, we used IPCC's key sectoral risk ranking (Table TS.4)[16], the best globally available ranking of risk across climate-change impacts and sectors. IPCC's risk categorisation was developed based on the following specific criteria: large magnitude, high probability, timing or irreversibility of hazard, persistent exposure or vulnerability contributing to risks, and limited potential to reduce risk through adaptation. We marked a sector as being at high global near-term risk if IPCC's Table TS.4[16] identifies an ecosystem or socio-economic sector (or the sector's services, as worded in Supplementary Information Tab 2.1) as being at *high* or *very high* risk of the climate-change impact with *current adaptation levels* and *high confidence*. To provide a relative ranking across different climate-change impacts, we analysed evidence on how certain climate-change impacts are likely to increase or decrease in frequency under a 1.5 versus 2°C scenario (Supplementary Information Tab 3.3). We present the global application of our systems framework with the global findings on where sectoral near-term risk is highest for those climate-change impacts likely to increase most in frequency under 1.5°C.

Limitations

There are many ways that sectors and services can be categorised. To provide a systems framework that is transferable across nations, we base our classification on an original land-cover/land-use classification (differentiating by ecosystems and socio-economic sectors). We categorised the services provided by each sector, acknowledging the difficulties with allocating services to ecosystems[60]. Instead of focusing on sectors and services, one might also focus on systems of receptors, as discussed in the literature[4]. We opted for the internationally-classified set, given our expectation that the framework can be applied with international and national accounting data across environmental and socio-economic sectors which is typically presented in the form of the sector categories applied (see SEEA[56]). We used a granular scale for the socio-economic sectors, as ISIC provides an overview of services linked to each sector. A similarly granular scale for ecosystems and the specific services associated with each ecosystem is not yet available, but is currently being developed by the SEEA. Future work should update the categories accordingly.

We focused on the climate-change impacts as defined by the IPCC AR5 report and acknowledge the absence of 'fire'[61] in this list. We did aim to mitigate this aspect by influences those climate-change influences whereby fires are exacerbated by droughts. Despite its limitations, we chose IPCC AR5 climate-change impacts as it is the only source of global evidence which includes multiple climate-change impacts and sectors.

Additionally, there are many ways that the range of adaptation options that are available could be characterised[62], so no characterisation is likely to be universally agreed upon. Following previous researchers [63,64], we acknowledge that adaptation includes (1) recognition activities (activities that demonstrate awareness), (2) groundwork activities (preliminary steps that inform action but do not constitute actual policy changes, such as vulnerability assessments or conceptual tools), and (3) adaptation action (tangible options taken to 'alter institutions, policies, programs, built environments, or mandates in response to experienced or predicted risks of climate change'). Given that the aim of the paper is to target specific adaptation options to inform national public adaptation decisions across sectors, we focused on the third category of adaptation actions with the aim of reducing risks of climate change.

This paper is based on evidence mapping of influences. For some influences between SDG targets and sectoral services, or between sectoral services and climate-change impacts there might not be published evidence yet. The absence of identified evidence does not mean the absence of an influence. Nevertheless, a focus on influences as captured in this paper are based on existing published evidence and are therefore replicable and supported.

It is possible for existing literature to make erroneous inferences on influences, especially when based on grey literature. Moreover, some climate-change impacts or SDG influences might be under-researched and therefore not identified. We aimed to mitigate this aspect by reviewing several studies for each influence and by discussing any potential issues or ambiguities with the authors of this paper, which span a range of disciplines and topical expertise (including geography, engineering, social science and ecology as well as topics from ecosystems & biodiversity, infrastructure, climate risk analysis, SDG target mapping, adaptation, amongst others). Moreover, it is also possible for sectors to have negative influences on the SDGs. Whilst we do not specifically assess trade-offs, our framework provides an indication where a sector's services *can* influence SDG targets, which can be used to identify negative influences. Additional research should also assess negative interdependent influences, for example to assess the effect of socio-economic sectors on ecosystems.

With respect to our global application, the identification of highest near-term risk is based on the best available evidence of changing hazard frequency (Supplementary Information Tab 3.3) and global sectoral near-term risk from the IPCC AR5[16]. Whilst this IPCC assessment is based on expert elicitation and only covers selected risk, it's use nevertheless provides a replicable and evidence-based overview of the type of sectoral risks to different climate-change impacts. The framework can be further applied to an updated overview of global sectoral risk from climate-change impacts, such as for example IPCC's AR6 or other global studies.

Data availability

The data that support the findings of this study are available within the paper and its Supplementary Information.

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Author Contributions

L.I.F. lead the study. L.I.F, S.T., and J.W.H. designed the study. L.I.F, R.H., S.T. and F.F-N. performed most of the analyses. L.I.F and J.W.H wrote most of the manuscript. All authors contributed to the manuscript through methodological advice, analysis, and feedback as well as figure and text edits.

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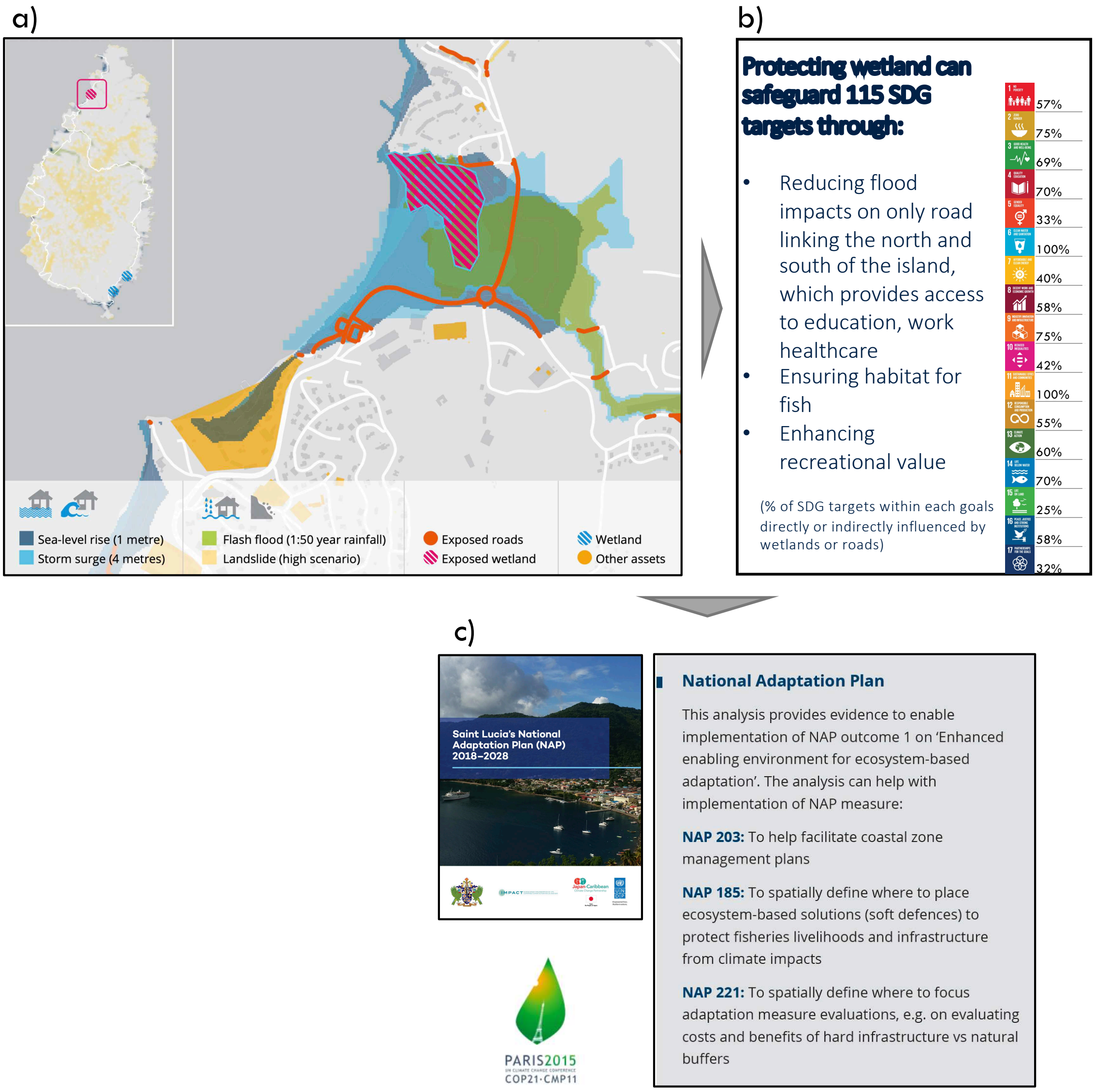

Extended Data Figure 2: Result from application of systems framework in Saint Lucia, where a) shows the exposure of Saint Lucia's wetlands to a 1-metre sea-level risk, a 4-metre storm surge and a 1:50 year rainfall flash flood event, b) the potential impact of adaptation, i.e. protecting this wetland for SDG targets, and c) how these results have been used to add spatial granularity to Saint Lucia's National Adaptation Plan (NAP).

Supplementary Table 1: Overview of SDG targets and indicators integrated in National Adaptation Plans (NAPs) (https://www4.unfccc.int/sites/NAPC/Pages/national-adaptation-plans.aspx), status: February 2021.

		Year of NAP	1) NAP mentions SDGs	2) NAP mentions targets of the SDGs	3) NAP mentions SDG indicators
Africa and Middle East	Burkina Faso	2015	No mention	No mention	No mention
	Cameroon	2015	No mention	No mention	No mention
	Ethiopia	2019	Some mention	No mention	No mention
	Kenya	2017	Some mention	No mention	No mention
	Togo	2018	Some mention	No mention	No mention
	Sudan	2016	Clearly mentioned in the context of a single sector	No mention	No mention
	Palestine	2016	No mention	No mention	No mention
Asia	Sri Lanka	2016	Clearly mentioned for all main sectors	Clearly mentioned for all main sectors	No mention
Pacific	Fiji	2018	Clearly mentioned for all main sectors	Clearly mentioned in the context of a single sector	No mention
	Kiribati	2020	Clearly mentioned for all main sectors	No mention	No mention
Caribbean	St. Lucia	2018	Clearly mentioned for all main sectors	No mention	No mention
	St. Vincent and the Grenadines	2019	Clearly mentioned for all main sectors	Clearly mentioned for all main sectors	Clearly mentioned for all main sectors
	Grenada	2019	Clearly mentioned for all main sectors	Some mention	Clearly mentioned for all main sectors
Latin America	Brazil	2016	Clearly mentioned in the context of a single sector	No mention	No mention
	Colombia	2018	No mention	No mention	No mention
	Chile	2017	No mention	No mention	No mention
	Guatemala	2019	Some mention	No mention	No mention
	Paraguay	2020	Clearly mentioned for all main sectors	No mention	No mention
	Suriname	2020	Clearly mentioned in the context of a single sector	No mention	No mention
	Uruguay	2019	Clearly mentioned in the context of a single sector	No mention	No mention

Legend:

- No mention
- Some mention
- Clearly mentioned in the context of a single sector
- Clearly mentioned for all main sectors

Methods for Supplementary Table 1:

We searched each NAP (https://www4.unfccc.int/sites/NAPC/Pages/national-adaptation-plans.aspx) - for the following search terms (based on the status of NAPs in January 2021):

1: NAP mentions SDGs

- for some mention: SDGs, Sustainable Development Goals, Agenda 2030
- clearly mentioned: SDGs, Sustainable Development Goals, Agenda 2030 & one sector: either agriculture, forest, water, energy, (other sectors as specific in (Supplementary Information (SI) 2.1)
- clearly mentioned for all main sectors: SDGs, Sustainable Development Goals, Agenda 2030 & more than one sector name, cross-cutting, cross-sectoral

2: NAP mentions the targets of the SDGs

- for some mention: SDG targets, development targets, sustainable development targets, Agenda 2030 targets
- clearly mentioned in the context of a single sector: SDGs, Sustainable Development Goals, Agenda 2030 & one sector: either agriculture, forest, water, energy, (other sectors as specific in SI 2.1)
- clearly mentioned for all main sectors: SDGs, Sustainable Development Goals, Agenda 2030 & more than one sector name: agriculture, forest, water, energy, (other sectors as specific in SI 2.1), cross-cutting, cross-sectoral

3: NAP mentions SDG indicators

- for some mention: SDG indicators, SDG targets, development targets, sustainable development targets, Agenda 2030 targets
- clearly mentioned in the context of a single sector: SDG indicators, SDG targets, development targets, sustainable development targets, Agenda 2030 targets & one sector: either agriculture, forest, water, energy, (other sectors as specific in SI (2.1))

- clearly mentioned for all main sectors: SDGs, Sustainable Development Goals, Agenda 2030 & more than one sector name: agriculture, forest, water, energy, (other sectors as specific in SI (2.1), cross-cutting, cross-sectoral

Supplementary Table 2: References for frequency variables for each climate change impact. See Supplementary Information Tab 3.3 for uncertainty bounds and full details.

Climate change impact	**Variable (change in frequency)**	**Source**
Extreme precipitation	Frequency of rainfall extremes over land (increase) (annual maximum 1-day precipitation globally over land that would be 1-in-20-year event in current climate)	(1) Kharin, V. V. et al. Risks from Climate Extremes Change Differently from 1.5°C to 2.0°C Depending on Rarity. Earth's Futur. 6, 704–715 (2018).
Damaging cyclone	Intense tropical cyclones (total category 4 and 5)	(1) Wehner, M. F., Reed, K. A., Loring, B., Stone, D. & Krishnan, H. Changes in tropical cyclones under stabilized 1.5 and 2.0 °C global warming scenarios as simulated by the Community Atmospheric Model under the HAPPI protocols. Earth Syst. Dyn. 9, 187–195 (2018).
Extreme temperature	Frequency of warm temperature extremes globally over land (annual daily maximum that would be a 1-in-20-year event in current climate)	(1) Kharin, V. V. et al. Risks from Climate Extremes Change Differently from 1.5°C to 2.0°C Depending on Rarity. Earth's Futur. 6, 704–715 (2018).
Flooding	Average river flow in 2100 change by 10% (variable: percentage of global land area seeing changes in average streamflow)	(1) Döll, P. et al. Risks for the global freshwater system at 1.5 °C and 2 °C global warming. Environ. Res. Lett. 13, 044038 (2018).
Precipitation	Average rainfall (relative to 1981-2010)	(1) Betts, R. A. et al. Changes in climate extremes, fresh water availability and vulnerability to food insecurity projected at 1.5°C and 2°C global warming with a higher-resolution global climate model. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 376, (2018).
Snow cover	Northern hemisphere snow extent in 2080s (annual)	(1) Wang, A., Xu, L. & Kong, X. Assessments of the Northern Hemisphere snow cover response to 1.5 and 2.0 °C warming. Earth Syst. Dyn. 9, 865–877 (2018).
Sea level	Median global sea level rise by 2100 (relative to 2000)	(1) Rasmussen, D. J. et al. Extreme sea level implications of 1.5 °C, 2.0 °C, and 2.5 °C temperature stabilization targets in the 21st and 22nd centuries. Environ. Res. Lett. 13, 034040 (2018).
Ocean acidification	Ocean acidity by 2050 (Percentage change in concentration of hydrogen ions, relative to 1986-2005)	(1) Nicholls, R. J. et al. Stabilization of global temperature at 1.5°C and 2.0°C: Implications for coastal areas. Philos. Trans. R. Soc. A Math. Phys. Eng. Sci. 376, (2018).
Drying trend	Drought months globally	(1) Naumann, G. et al. Global Changes in Drought Conditions Under Different Levels of Warming. Geophys. Res. Lett. 45, 3285–3296 (2018).

Figures

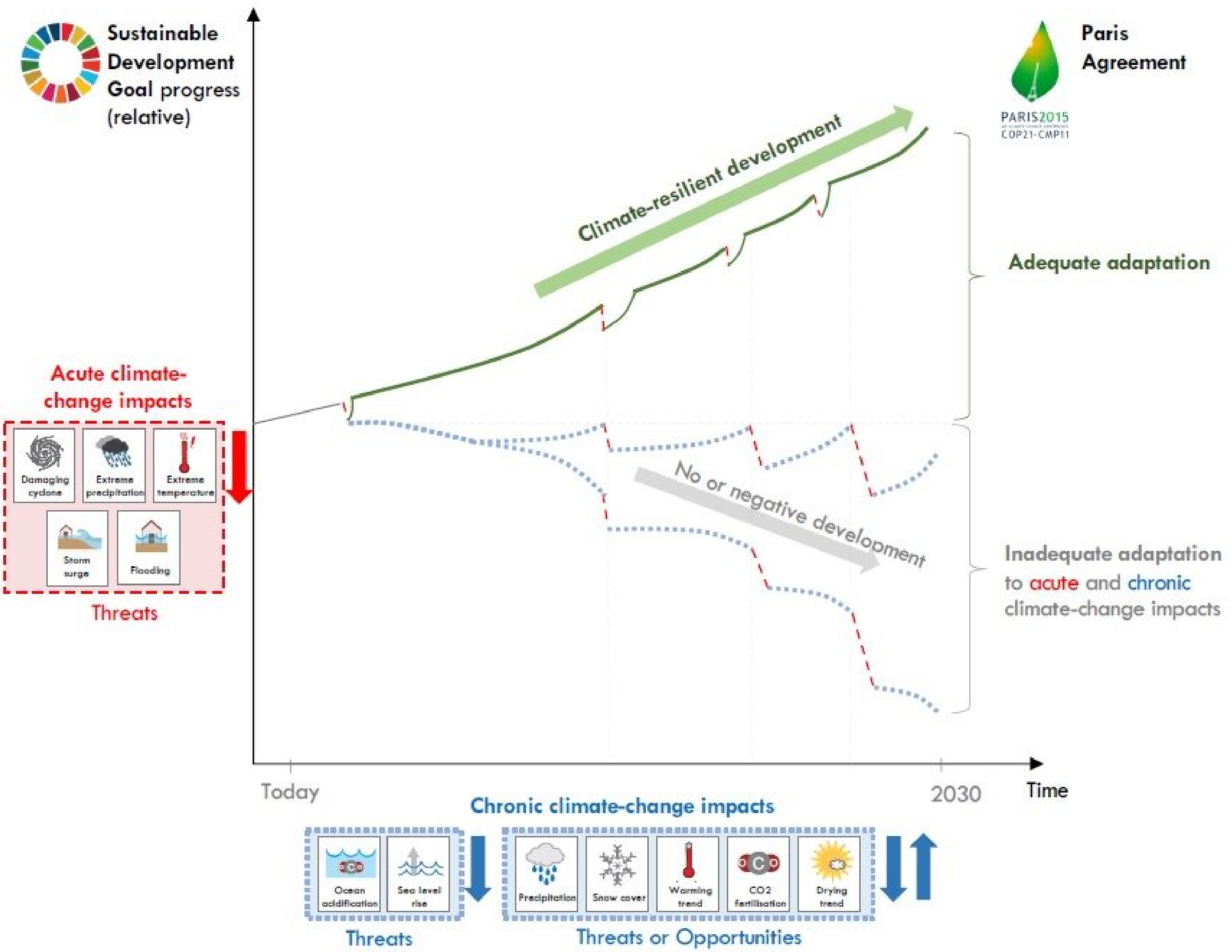

Figure 1

Action on adaptation (green bold lines) safeguards achievement of the Paris Agreement and the Sustainable Development Goals (SDGs) in the 2030 timeline. Inaction on adaptation to acute climate-change impacts (damaging cyclones or flooding) can threaten progress of the global agreements at one point in time (red dashed lines), whilst inaction on adaptation to chronic climate-change impacts (ocean acidification or dying trend) can materialise as threats or opportunities to progress on the global agreements (blue dashed lines). List of climate-change impacts is adopted from the IPCC16.

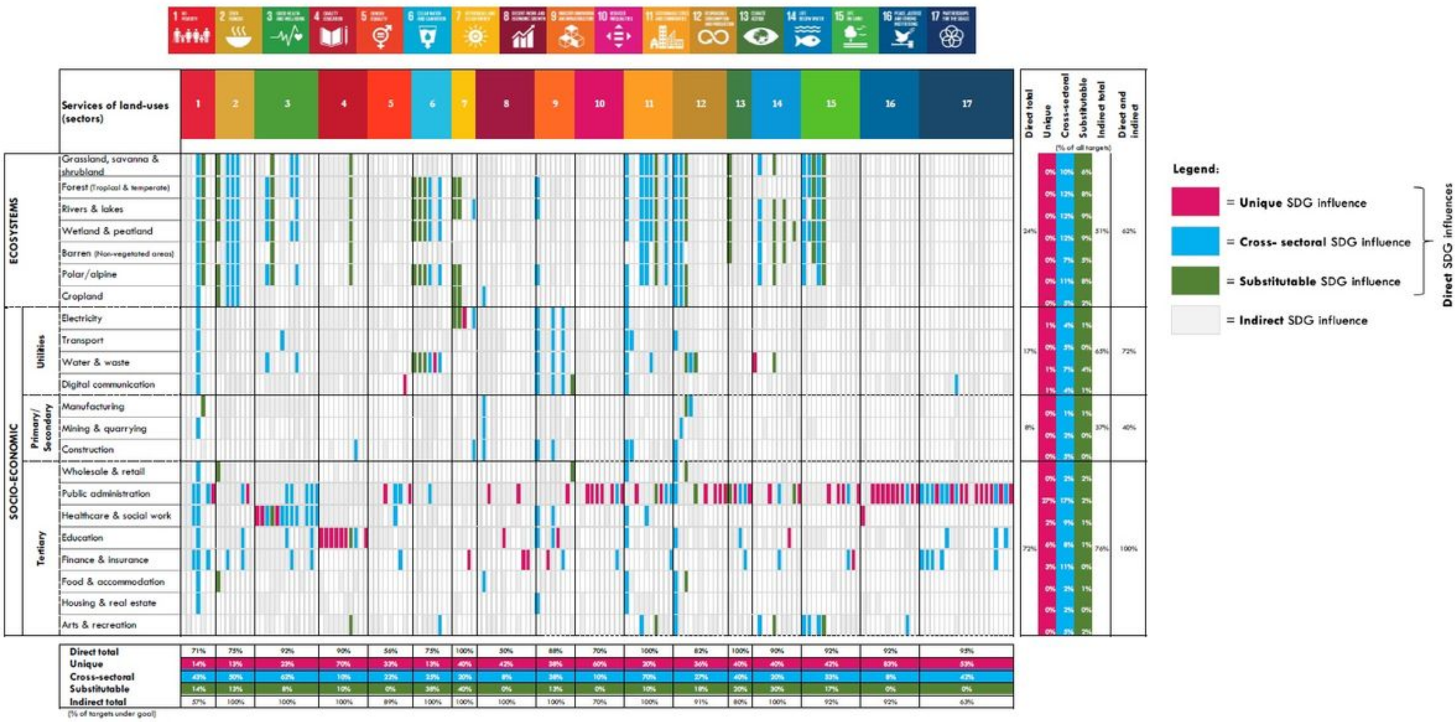

Figure 2

SDG targets influenced by ecosystems and socio-economic sectors. Each rectangle represents one SDG target; magenta shading denotes a unique direct influence; blue represents a cross-sectoral direct influence; and green denotes a substitutable direct influence for achieving the SDG target. Grey indicates an indirect influence, where there is published evidence that improving the quality/quantity of the sector's services can help achieve the SDG target. White shading indicates the absence of identified evidence. Evidence is reported in Supplementary Information Tab 3.1.

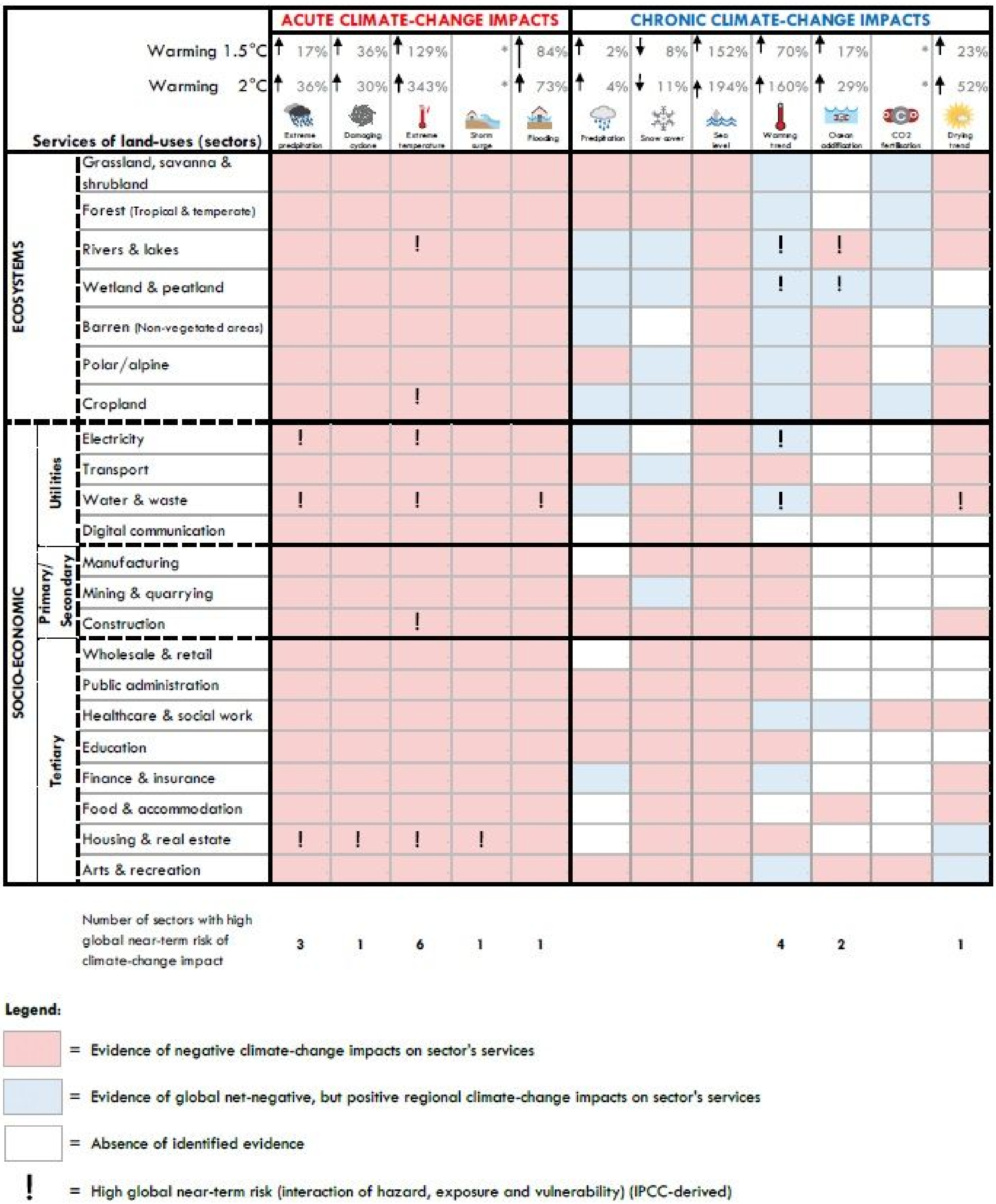

Figure 3

Ecosystems and socio-economic sectors influenced by acute and chronic climate-change impacts. Red shading denotes evidence of a negative impact, blue shading highlights a global net-negative impact, but potential positive regional effect of climate-change impact on services. White shading indicates the absence of identified evidence. Evidence is reported in Supplementary Information Tab 3.2. Exclamation marks represents high near-term risk based on IPCC AR5 TS.416. Percentages for climate-change impacts signify changes in frequency under a 1.5 and 2°C scenario (see Supplementary Table 2 and Supplementary Information Tab 3.3), whereby the symbol * suggests that no quantified evidence was identified.

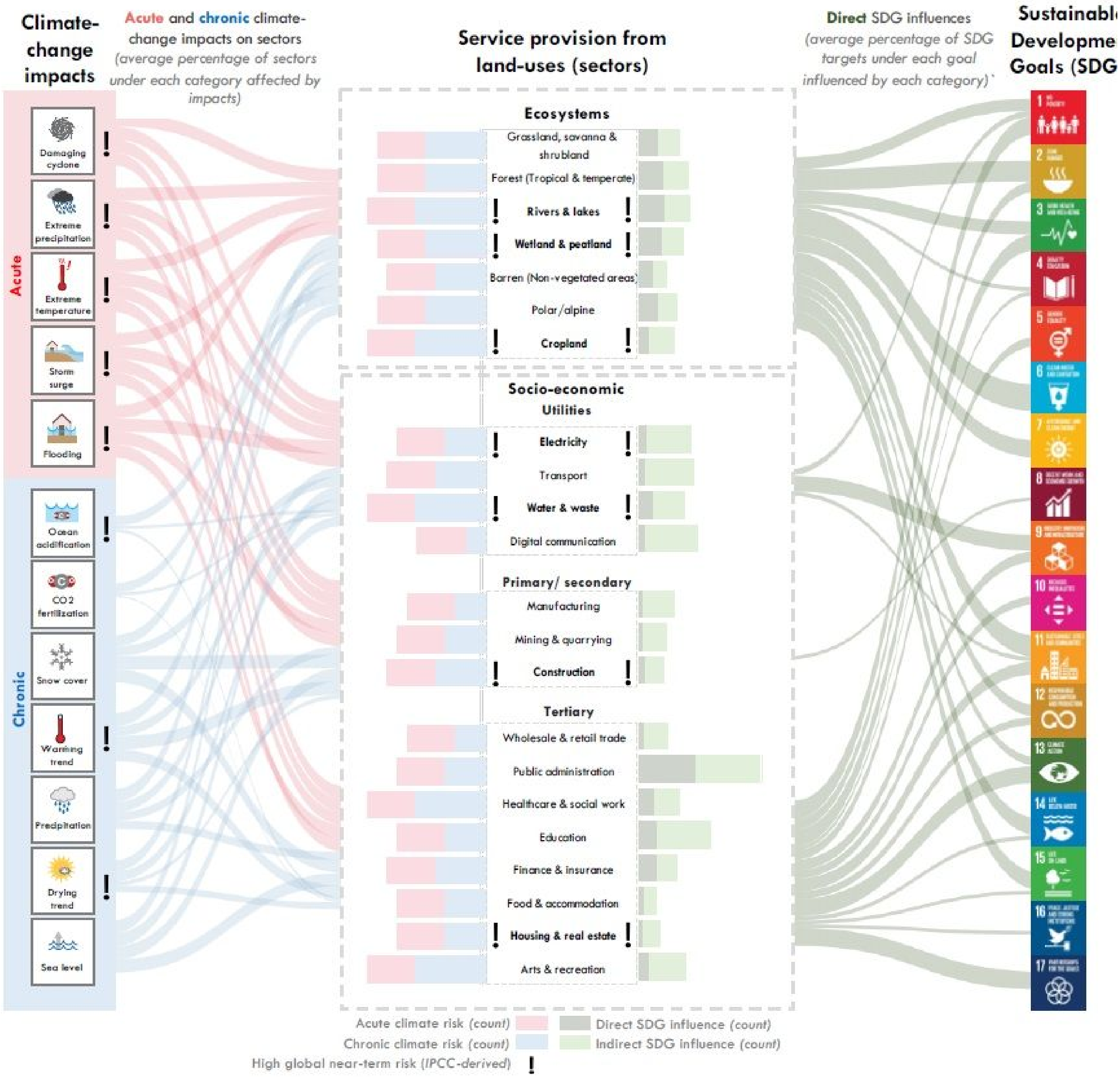

Figure 4

Systems framework, showing (from left to right): Percentage of sectors under each category (ecosystems, utilities, primary/secondary, tertiary) impacted by acute (red Sankey lines) and chronic climate-change impacts (blue Sankey lines); quantity of acute (red bars) and chronic climate-change impacts (blue bars) on sectors; quantity of direct (dark green bars) and indirect SDG target influences (light green bars) from sectors; and the percentage of SDG targets under each goal directly influenced (green Sankey lines) by each sector category. Exclamation marks (left) denote high global near-term risk16.

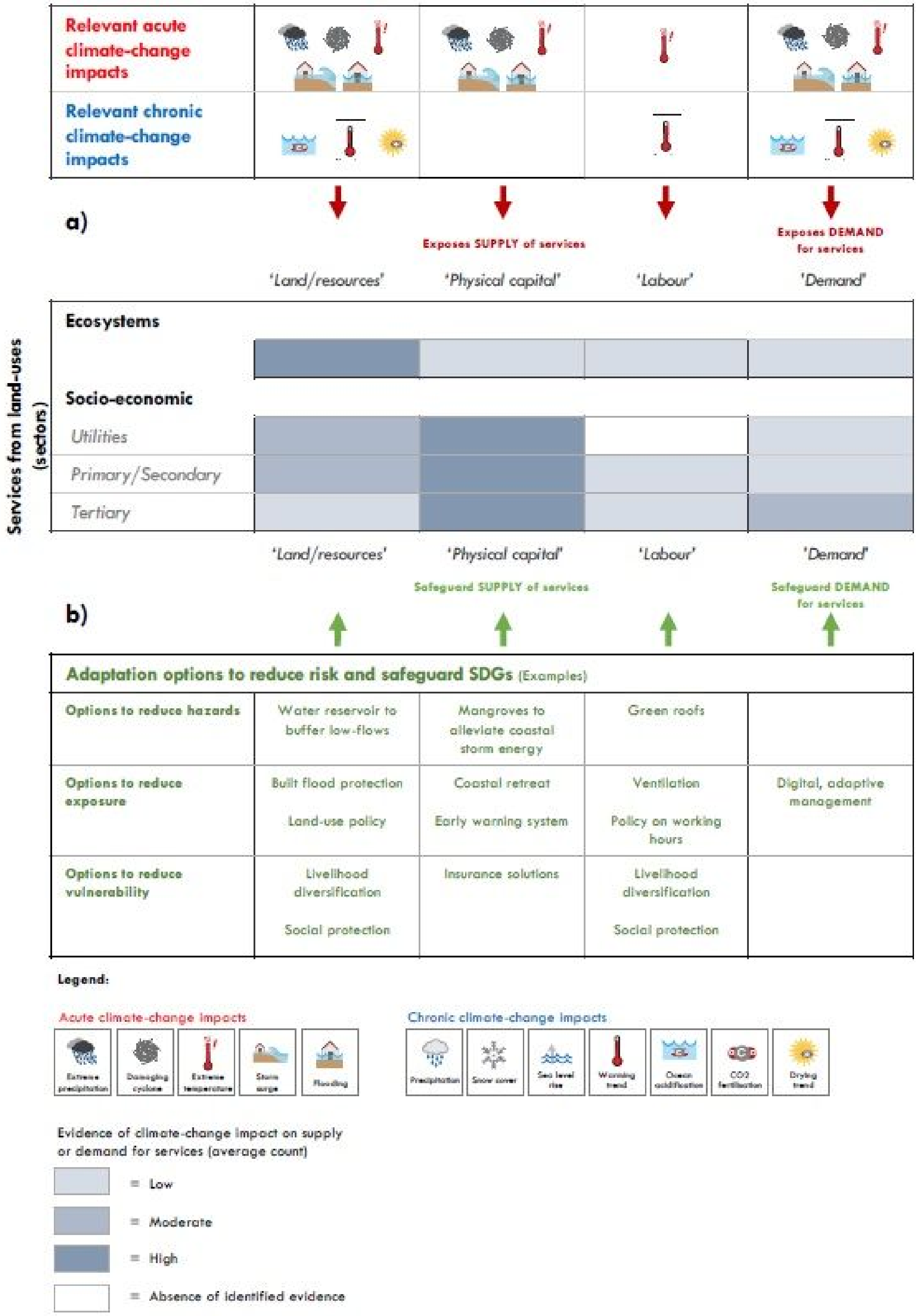

Figure 5

Tailoring adaptation to climate-change impacts. Example adaptation options applicable to acute and chronic climate-change impacts, based on average count of evidence on how climate-change impacts affect ecosystems and socio-economic sectors. Absence of colour indicates the absence of identified evidence. a) Effects of acute and chronic climate-change impacts on supply of and demand for services of different sector categories; b) Ability of adaptation options to safeguard service provision in the face of climate-change impacts. The example list of adaptation options is not extensive.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- CCadaptationSDGssupplementaryinformationFuldauer2021.xlsx