6SM

Cities, Settlements and Key Infrastructure
Supplementary Material

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Table of Contents

SM6.1 Introduction

This Chapter 6 Supplementary Material overviews the methodology and documents the assessment of the literature underlying Table 6.6: Urban climate-resilient development, in Chapter 6: Cities, Settlements and Key Infrastructure. This is a first global assessment of the observed contribution to elements of climate-resilient development from adaptation measures routinely deployed in urban contexts. The assessment is on observed consequences, not theoretical or anticipated. This constrains the literature, and some entries have no sources, making an assessment impossible at this time.

SM6.2 Methods

From Chapter 17, climate-resilient development is that which deliberately adopts mitigation and adaptation measures to secure a safe climate, meet basic needs, eliminate poverty and enable equitable, just and sustainable development. It halts practices causing dangerous levels of global warming and may involve deep societal transformation to ensure well-being for all.

Climate-resilient development components used here build on the framing provided by Chapter 17 that identifies: benefits to humans, benefits to ecosystems, potential effectiveness, contributions to greenhouse gas emissions reduction, equity benefits and transformations towards sustainable development. To these we add 'risk coverage'; this allows a consideration of the consequences of specific urban adaptation measures on the generation/reduction of vulnerability and hazard exposure. We further differentiate based on the literature included in Chapters 6 and 17 to identify 17 components of climate-resilient development. These components are high level and could be further sub-divided. The final choice of these components reflects the state of the literature and the desire to provide an analysis that is meaningful to policy actors. The components identified and definitions are presented below:

SM6.2.1 Component Terms

SM6.2.1.1 Risk Coverage

Addresses multiple hazards: Influences risk (exposure, vulnerability and capacity) to more than one climate-associated hazard (e.g., flood, heat/cold, storm, fire, sea level rise, wind, food and water security).

Reduces systemic vulnerability: Reduces physical or social vulnerability with relevance to climate-related hazards and at least one more risk type (e.g., pandemic, economic shock, industrial pollution, political instability).

Constrains knock-on hazard generation: Changes behaviour, livelihood or population location with implications for hazard exposure (e.g., new seawalls might encourage an exaggerated sense of security attracting new formal or informal housing and so inadvertently generate new hazard exposure).

Constrains transfer of risk to other people and places: Can shift hazard, exposure, vulnerability or capacity to other places/people (e.g., insurance can lead to a sharing of risk that reduces extremes of vulnerability; seawalls can disrupt sediment transport producing erosion and flood risk in neighbouring locations).

SM6.2.1.2 Benefits to Humans

Enhances social capital: Builds trust, organisational capacity and communication (e.g., community-based actions can strengthen local social ties of familiarity and trust).

Enhances livelihoods: Enhances livelihood opportunities including in the construction and maintenance of an intervention and as an outcome of the intervention (e.g., nature-based solutions such as mangroves can enable non-traditional forestry products).

Enhances health: Enhances health and well-being beyond direct benefits of the intervention (e.g., improved sanitation enhances health to many communicable diseases in addition to preventing unsanitary flood events).

SM6.2.1.3 Benefits to Ecosystems Services

Ecological benefit: Enhances environmental protection, restoration or expands green/blue space (e.g., mangrove stands deployed to reduce flood risk also expand mangrove ecosystems).

SM6.2.1.4 Potential Effectiveness

Flexibility post-deployment: Intervention can be adapted to respond to new risk or development conditions (e.g., social safety net payments can be adjusted in line with variation in the cost of living).

Deployable at scale: The impact of single or programmed interventions is observed to reduce risk at the city scale (e.g., comprehensive adaptation of health systems to maintain full provision during disaster events).

Benefits adaptation in other infrastructure systems: Enhances the resilience of connected, downstream infrastructure (e.g., energy generation infrastructure, when adapted well enhances the resilience of information technology systems).

Economic cost: Capacity of medium income city (i.e., a millionaire city in a middle-income country) compared with the economic costs for comprehensive deployment (e.g., comprehensive re-design of urban road infrastructure to cope with temperature and flood risks may exceed municipal budgets).

SM6.2.1.5 Contributions to Greenhouse Gas Emissions Reduction

Climate mitigation co-benefit: Contributes to reduced greenhouse gas emissions or reduces embedded carbon (e.g., tree planting to reduce flood risk or ameliorate temperature extremes can also absorb carbon).

SM6.2.1.6 Equity Benefits

Reduces poverty and marginality: Explicitly designed to reduce economic poverty and social marginalisation.

Inclusive and locally accountable: The adaptation technology has qualities that enable public transparency, local accountability and stakeholder inclusive design, implementation and monitoring (e.g., community-based resilience including neighbourhood drain cleaning is strongly inclusive, transparent and accountable).

SM6.2.1.7 Transformations towards Sustainable Development

Enables social transformation: Observed fundamental, progressive change in the distribution of ownership and wealth and in power relations within legal/political and social/cultural systems (e.g., diversifying urban livelihoods brings new spending power to women enhancing public status and voice).

Enables ecological transformation: Observed fundamental change in socioecological relationships and approaches to nature enhancing the viability of ecosystems and their long-term sustainability (e.g., large-scale investment in reforestation of urban watersheds to reduce flash flooding turns waste land into forest).

SM6.2.2 Assessment Methodology

The choice of adaptation measures used in the analysis was driven by the major headings in Section 6.3. Each measure represents a diverse multiplicity of local applications. As with climate-resilient development pathway (CRDP) components, the list of adaptation measures to be reviewed could have been much longer; we made a final selection based on the balance of available literature and policy actor relevance. Inevitably though this brings a compromise and there will be deviation in results between individual deployment of a specific measure and the aggregated results presented here.

Assessment of the literature was by Chapter 6 lead authors and contributing authors. The assessment of nature-based solutions deployed technical support from a research team coordinated by a Chapter 6 lead author. Before making assessments of the literature, each climate-resilient development component, score and confidence scale were explained and discussed. Experts were asked to make a judgement on the preponderance of contemporary empirical evidence; to consider literature reviewed in AR6 and extend this where necessary. The accompanying statements are fully referenced. Judgements were based on the best observed deployment of solutions. This introduces a positive bias to the analysis. Theoretical or planned actions were not included, often, especially for social policy interventions, accounts of impact were generalised or based on theoretical assumption more than empirical observation, and these accounts were not included in the analysis. Thus, for some social policy adaptations while there is strong general support for positive consequences, the empirical evidence is slim or focused on critique leading to a lower score than might be expected.

The score ranges were as follows: positive high; positive moderate; positive small; positive negligible; nil; negative negligible; negative small; negative moderate, negative high; no data. Final scores were the decision of the expert reviewers.

For each entry, experts also noted the extent and degree of agreement in the literature: high agreement – limited evidence; high agreement – medium evidence; high agreement – robust evidence; medium agreement – limited evidence; medium agreement – medium evidence; medium agreement – robust evidence; low agreement – limited evidence; low agreement – medium evidence; low agreement – robust evidence

Assessments were submitted by authors and then collated and checked centrally, and small adjustments to scores, confidence and underlying text were made in consultation with authors. Moderation meetings were held between section teams and the assessment lead author.

SM6.3 Supporting Statements

SM6.3.1 Social Infrastructure

SM6.3.1.1 Land-Use Planning (see Section 6.3.2.1)

SM6.3.1.1.1 Multiple climate hazards: positive high (high agreement, robust evidence)

Climate hazards such as extreme heat and humidity, extreme precipitation, coastal flooding and drought vulnerability may all be impacted by the imposition of land use planning tools (Güneralp et al., 2015). Additional hazards include sea level rise and the urban heat island effect (Carter et al., 2015; Larsen, 2015; Anguelovski et al., 2016; Nolon, 2016; Nalau and Becken, 2018; Perera and Emmanuel, 2018). Land use planning has the potential to benefit these environmental concerns; however, disaster risk reduction has been seldom acknowledged within national planning programmes (Jabareen, 2015).

SM6.3.1.1.2 Systemic vulnerability reduction: positive small (high agreement, robust evidence)

Climate-related risks frequently threaten disadvantaged and vulnerable populations and can force environmental migration (Heslin et al., 2019; Luetz and Merson, 2019; Plänitz, 2019). Both slow and rapid onset events pose a risk to vulnerable populations (Silja, 2017; Heslin et al., 2019); however, land use planning and zoning measures may mitigate these events and act in opposition to climate gentrification (Anguelovski et al., 2016; Butler et al., 2016; Keenan et al., 2018; Lyles et al., 2018; Marks, 2015).

SM6.3.1.1.3 Reduces new hazard exposure generated: positive high (high agreement, robust evidence)

In conjunction with ecosystem-based adaptations (e.g., for flood management and curbing the urban heat island effect) (Carter et al., 2015; Larsen, 2015; Anguelovski et al., 2016; Nolon, 2016; Nalau and Becken, 2018; Perera and Emmanuel, 2018); community-based adaptations (trade-offs and valuations, i.e., which land uses are valued more) (Carter et al., 2015; Larsen, 2015; Anguelovski et al., 2016; Nolon, 2016; McPhearson et al., 2018; Nalau and Becken, 2018; Perera and Emmanuel, 2018); and built form regulations and codes (Larsen, 2015; León and March, 2016; Nolon, 2016; Yiannakou and Salata, 2017; Perera and Emmanuel, 2018; Straka and Sodoudi, 2019), the implementation of land use planning tools can be directly guided towards reducing hazard exposure.

SM6.3.1.1.4 Transfer of risk/impacts to other areas/people: negative negligible (high agreement, robust evidence)

Conventional zoning regulations and land use planning, whether at the regional or the local scales, deploy protection, accommodation or retreat methods to minimise, or altogether eliminate, slow and/or rapid onset risks. The evidence indicates that risk-eliminating retreat measures are less widely adopted (Anguelovski et al., 2016; Butler et al., 2016; Lyles et al., 2018) due to the controversies of relocation and to the complexities of buyouts (Butler et al., 2016; King et al., 2016).

SM6.3.1.1.5 Social capital: positive high (high agreement, robust evidence)

Land use planning guides the administration of space and can adapt to better suit a region's population. Fundamentally, Euclidean zoning has the potential to protect, accommodate and remove people from certain scenarios which helps to encourage a safe and continuous inhabitation (Butler et al., 2016; León and March, 2016; Lyles et al., 2018). Further planning tools are also contributory to the strengthening of social capital, namely ecosystem-based adaptations (Anguelovski et al., 2016; Carter et al., 2015; Larsen, 2015; Nalau and Becken, 2018; Nolon, 2016; Perera and Emmanuel, 2018); community-based adaptations (Anguelovski et al., 2016; Carter et al., 2015; Larsen, 2015; McPhearson et al., 2018; Nalau and Becken, 2018; Nolon, 2016; Perera and Emmanuel, 2018); and built form regulations (Larsen, 2015; León and March, 2016; Nolon, 2016; Perera and Emmanuel, 2018; Straka and Sodoudi, 2019; Yiannakou and Salata, 2017). Moreover, planning tools such as scenario planning, flexible zoning and development incentivisation (United States Environmental Protection Agency, 2017) can bolster and refine the means and modes of urban development, and the subsequent continuity of social capital.

SM6.3.1.1.6 Livelihoods: positive high (high agreement, robust evidence)

Euclidean zoning regulations and land use planning are instrumental in risk minimisation. Protection, accommodation and retreat are all modes of urban control that are (most commonly) imposed to improve the livelihoods of citizens. This may include the development of protective infrastructure, the modification of the land to better accommodate and react to change, or the relocation of people (Butler et al., 2016; León and March, 2016; Lyles et al., 2018).

SM6.3.1.1.7 Health: positive high (high agreement, robust evidence)

Cascading benefits of zoning and land use planning for climate adaptation are associated with the use of soft land cover, green infrastructure and improvement of liveability through better conditions for walkability and cycling (Smith et al., 2017). This decreases auto dependency and contributes to a population's overall health (Carter et al., 2015; Larsen, 2015).

SM6.3.1.1.8 Ecological: positive high (high agreement, robust evidence)

Planning tools can be established to ensure the continuity of ecosystem services. For instance, landscape protection (one of three major portions of the Euclidean zoning system) can prohibit urban development, which has the potential to reduce the loss of ecosystem services (Butler et al., 2016; León and March, 2016; Lyles et al., 2018). Moreover, the increase in soft land cover and green infrastructure also contributes to mitigation through air quality enhancement, energy conservation and carbon sequestration, while its ecological benefits include the preservation and expansion of habitats (Carter et al., 2015; Larsen, 2015).

SM6.3.1.1.9 Flexibility post-deployment: positive high (high agreement, robust evidence)

Land use planning and zoning may be bolstered by additional, more concisely derived planning media such as ecosystem-based adaptation (Anguelovski et al., 2016; Carter et al., 2015; Larsen, 2015; Nalau and Becken, 2018; Nolon, 2016; Perera and Emmanuel, 2018); community-based adaptations (Anguelovski et al., 2016; Carter et al., 2015; Larsen, 2015; McPhearson et al., 2018; Nalau and Becken, 2018; Nolon, 2016; Perera and Emmanuel, 2018); and built form regulations (Larsen, 2015; León and March, 2016; Nolon, 2016; Perera and Emmanuel, 2018; Straka and Sodoudi, 2019; Yiannakou and Salata, 2017). Although not necessarily vectors of flexibility, they offer a more holistically focused system with widespread intentions and delegations. In essence, therefore, a robust land use programme can be equipped to manage a myriad of possible issues and concerns, and effectively adapt to meet the needs of a location and its population.

SM6.3.1.1.10 Deployable at scale: positive high (high agreement, medium evidence)

Land use planning initiatives are deployable at a large scale; however, effectiveness may vary between jurisdictions. One or a combination of: lack of clarity of implementation strategies for climate adaptation, lack of funding, competing priorities (especially among professional planners and politicians), and institutional challenges face mainstreaming adaptation through land use planning whether through municipal or regional plans. This evidence spans cities in the Global South equally as in richer countries (see Jabareen's 2015 study of 20 cities globally). These factors impact jurisdictions differently and are a source of discrepancy when it comes to global scalability.

SM6.3.1.1.11 Benefit to other infrastructure systems adaptation: positive moderate (high agreement, medium evidence)

One of the primary roles of land use planning is to guide the development of the urban form. As such, it underpins and establishes the basis for other infrastructure systems such as physical infrastructure and nature-based solutions (Morrissey et al., 2018).

SM6.3.1.1.12 Economic feasibility: positive high (high agreement, robust evidence)

Land use planning is a commonly applied practice globally and is frequently ratified at a provincial and/or federal level. Funding, however, is a major impediment to effective land use planning (Jabareen, 2015), although improving liveability has been proven to boost economic development and property value (Carter et al., 2015; Larsen, 2015).

SM6.3.1.1.13 Mitigation co-benefit: positive high (high agreement, robust evidence)

The increase in soft land cover and green infrastructure also contributes to mitigation through air quality enhancement, energy conservation and carbon sequestration, while its ecological benefits include the preservation and expansion of habitats (Carter et al., 2015; Larsen, 2015).

SM6.3.1.1.14 Targets poverty and marginality: negative small (medium agreement, limited evidence)

Land use planning must be approached cautiously as it may contribute to marginalisation, especially by means of climate gentrification (Keenan et al., 2018; Marks, 2015) and population relocation which may prevail in certain Euclidean retreat-based approaches (Butler et al., 2016; King et al., 2016). When approached and imposed carefully, however, land use planning can be an effective tool in mitigating urban marginalisation.

SM6.3.1.1.15 Inclusive and locally accountable: positive moderate (high agreement, medium evidence)

Contemporary planning paradigms, such as participatory planning, are targeted towards enhancing the voice of the greater population through decision making processes (Hardoy et al., 2019). In conventional land use and zoning practices, regulations are frequently applied at the local or regional level which directly forges a degree of accountability for decision makers; the public and those who make decisions that impact them are inseparable (Butler et al., 2016; León and March, 2016; Lyles et al., 2018).

SM6.3.1.1.16 Social transformation: positive high (high agreement, medium evidence)

The spill-over benefits produced by land use planning and zoning include an increase in green and blue land covering, aesthetic improvements made to urban areas and liveability improvements such as the enhancement of active transportation networks (Carter et al., 2015; Larsen, 2015). In addition, planning regulations can proactively adapt to and accommodate changing environmental conditions, enabling socially beneficial, sustainable development (Butler et al., 2016; León and March, 2016; Lyles et al., 2018).

SM6.3.1.1.17 Ecological transformation: positive high (high agreement, medium evidence)

Ecologically, there are spill-over benefits of deploying zoning and land use planning for climate adaptation. Mostly, the increase in soft land cover and green infrastructure also contributes to mitigation through air quality enhancement, energy conservation and carbon sequestration, while its ecological benefits include the preservation and expansion of habitat (Carter et al., 2015; Larsen, 2015).

SM6.3.1.2 Livelihoods and Social Protection (see Section 6.3.2.2)

SM6.3.1.2.1 Multiple climate hazards: positive high (high agreement, medium evidence)

Safety nets protect vulnerable households from impacts of economic shocks, natural disasters and other crises. Adaptive social protection (ASP) has been an emerging strategic tool to integrate poverty reduction, disaster risk reduction and humanitarian development into adaptation to climate change (Watson et al., 2016; Béné et al., 2018a; Aleksandrova, 2019) and thus influences risk to multiple climate hazards. ASP has been justified as an effective instrument to build resilience to climate extremes and slow-onset climate events such as sea level rise and environmental degradation (Schwan and Yu, 2018; Aleksandrova, 2019).

SM6.3.1.2.2 Systemic vulnerability reduction: positive high (high agreement, robust evidence)

ASP has been justified as an effective instrument to build resilience to climate extremes and slow-onset climate events such as sea level rise and environmental degradation (Schwan and Yu, 2018; Aleksandrova, 2019). ASP can also facilitate long-term change and adaptation by improving education and health levels, as well as providing a proactive approach to managing climate-induced migration in both rural and urban areas (Adger et al., 2014; Schwan and Yu, 2018). Some examples from China show social protection can improve adaptive capacity of urban communities with social medical insurance, damaged risky housing subsidies, weather-index insurance, post-disaster construction, relocation planning, livelihood shift strategies, and so on (Pan et al., 2015; Zheng et al., 2018; Rao and Li, 2019).

SM6.3.1.2.3 Reduces new hazard exposure generated: positive moderate (high agreement, medium evidence)

ASP can act as a crucial complement to risk management tools provided by communities and markets, tools which tend to be insufficient in the face of large or systemic shocks, by providing predictable transfers, developing human capital and diversifying livelihoods (Hallegatte et al., 2016).

SM6.3.1.2.4 Transfer of risk/impacts to other areas/people: negative-negligible (high agreement, limited evidence)

Social protection may lead to maladaptation when the long-term impacts of climate change are not mainstreamed into urban risk planning. This could lead to risk transfer downstream (Hallegatte et al., 2016).

SM6.3.1.2.5 Social Capital: positive small (high agreement, limited evidence)

To deal with short-term vulnerability to climate shocks, ASP can act as a crucial complement to risk management tools provided by communities and markets, tools which tend to be insufficient in the face of large or systemic shocks, by providing predictable transfers, developing human capital and diversifying livelihoods (Hallegatte et al., 2016). ASP can also facilitate long-term change and adaptation by improving education and health levels, as well as providing a proactive approach to managing climate-induced migration in both rural and urban areas (Adger et al., 2014; Schwan and Yu, 2018).

SM6.3.1.2.6 Livelihoods: positive moderate (high agreement, medium evidence)

To deal with short-term vulnerability to climate shocks, ASP can act as a crucial complement to risk management tools provided by communities and markets, tools which tend to be insufficient in the face of large or systemic shocks, by providing predictable transfers, developing human capital and diversifying livelihoods (Hallegatte et al., 2016). ASP can also facilitate long-term change and adaptation by improving education and health levels, as well as providing a proactive approach to managing climate-induced migration in both rural and urban areas (Adger et al., 2014; Schwan and Yu, 2018). Some examples from China show social protection can improve adaptive capacity of urban communities with social medical insurance, damaged risky housing subsidies, weather-index insurance, post disaster construction, relocation planning, livelihood shift strategies, and so on (Pan et al., 2015; Zheng et al., 2018; Rao and Li, 2019).

SM6.3.1.2.7 Health: positive moderate (high agreement, limited evidence)

ASP can also facilitate long-term change and adaptation by improving education and health levels (Adger et al., 2014; Schwan and Yu, 2018).

SM6.3.1.2.8 Ecological: positive negligible (low agreement, limited evidence)

May be evidence of local food production/organic food as part of safety net with reduced embedded carbon (Smith et al., 2019, Stein and Santini, 2021). However, local food production is not simply equated with sustainability and does not necessarily result in lower carbon footprint (Stein and Santini, 2021).

SM6.3.1.2.9 Flexibility post-deployment: positive small (medium agreement, medium evidence)

Countries at all income levels can set up ASP systems that increase resilience to natural hazards, but the systems need to identify cost–benefits and be scalable and flexible to adjust to future, increasing climate risk (Agrawal et al., 2019; Hallegate et al., 2016). Social protection and social safety nets such as food stamps and housing subsidies can be adapted.

SM6.3.1.2.10 Deployable at scale: positive moderate (high agreement, medium evidence)

ASP can contribute to both incremental and transformative interventions both at the system level (short-term and long-term coping strategies from communities) and at the beneficiaries' level (vulnerable populations) (World Bank, 2015; Béné et al., 2018a; Aleksandrova, 2019).

SM6.3.1.2.11 Benefit to other infrastructure systems adaptation: positive small (high agreement, limited evidence)

Livelihood support can be a component of supporting local economies during crisis and post disaster (Daly et al., 2020).

SM6.3.1.2.12 Economic feasibility: positive moderate (medium agreement, medium evidence)

Countries at all income levels can set up ASP systems that increase resilience to natural hazards, but the systems need to identify cost–benefits and be scalable and flexible to adjust to future, increasing climate risk. ASP systems can be cost effective and equitable when targeting accuracy, timely risk sharing (disaster assistance) and improved policy coherence. Traditional disaster assistance is not as timely and cost effective, especially for providing response to slow-onset disasters or low-probability, high-impact extreme events. Index-based risk sharing (i.e., weather insurance) is emerging to meet the gap and pre-finance expected disasters. For example, introducing a public–private insurance mechanism in Austria has had a noticeable impact on the total monetary burden, causing it to fall by ~50% for regional governments with disaster risk reduction incentives (Unterberger et al., 2019).

SM6.3.1.2.13 Mitigation co-benefit: positive negligible (low agreement, limited evidence)

Where local food systems or organic consumption are promoted, this can have an impact on embedded carbon (Smith et al., 2019, Stein and Santini, 2021), but this is rarely intentional within ASP programme aims.

SM6.3.1.2.14 Targets reducing poverty and marginalisation: positive high (high agreement, medium evidence)

Social protection, or social security, is defined as the set of policies and programmes designed to reduce and prevent poverty and vulnerability throughout the lifecycle (ILO, 2017). It is estimated that 36% of the very poor escaped extreme poverty because of social safety nets

(Ivaschenko et al., 2018). ASP may be very good at reducing extreme poverty by helping to meet individual or household needs. Carter and Janzen (2018) find that the long-term level and depth of poverty can be improved by incorporating vulnerability targeted social protection into a conventional social protection system.

SM6.3.1.2.15 Inclusive and locally accountable: positive moderate (medium agreement, robust evidence)

ASP systems can be cost effective and equitable when targeting accuracy, timely risk sharing (disaster assistance) and improved policy coherence. Inclusive, targeted, responsive and equitable social protection can support long-term transformations toward more sustainable, adaptive and resilient societies (Adger et al., 2014; Hallegatte et al., 2016; Béné et al., 2018a; Carter and Janzen, 2018; Shi et al., 2018).

SM6.3.1.2.16 Social transformation: positive moderate (medium agreement, medium evidence)

The spill-over benefits produced by land use planning and zoning include an increase in green and blue land covering, aesthetic improvements made to urban areas and liveability improvements such as the enhancement of active transportation networks (Carter et al., 2015; Larsen, 2015). In addition, planning regulations can proactively adapt to and accommodate changing environmental conditions, enabling socially beneficial, sustainable development (Butler et al., 2016; León and March, 2016; Lyles et al., 2018).

SM6.3.1.2.17 Ecological transformation: positive negligible (low agreement, limited evidence)

Where local food systems or organic consumption are promoted, this can have an impact on embedded carbon, but this is rarely intentional within ASP programme aims.

SM6.3.1.3 Emergency Management and Security (see Section 6.3.2.3)

SM6.3.1.3.1 Multiple climate hazards: positive moderate (high agreement, medium evidence)

Much of the organisational structures of emergency management are designed to be applied to a range of events, including public awareness, emergency planning and business continuity planning (Twigg, 2013; Lumbroso et al., 2016; Tyler and Sadiq, 2019).

SM6.3.1.3.2 Systemic vulnerability reduction: positive moderate (medium agreement, medium evidence)

Climate risks pose livelihood threats for vulnerable and marginal populations. Systemic vulnerability reduction to such risks can be limited by certain emergency management measures, such as early-warning systems, which remain widely insufficient and the complexity of urban landforms makes accurate and detailed early warning difficult (Jones et al., 2015). However, effective measures such as installation of drinking water and food storage facilities in cyclone or flood prone areas have the direct benefit of reducing physical and/or social vulnerabilities to climate-related risks and can have co-benefits for reducing or mitigating other risk types such as economic shock and health impacts (Lumbroso et al., 2016; Magee et al., 2016; Marchezini et al., 2017).

SM6.3.1.3.3 Reduces new hazard exposure generated: positive high (medium agreement, medium evidence)

Emergency planning and disaster risk management measures implemented to reduce social and physical vulnerability to a specific risk such as flooding or fire, often have co-benefits for reducing exposure to other hazards (Thomas et al., 2019). Public engagement and ICTs for emergency management, building codes, education and communication and other risk management measures can be targeted to account for reducing exposure to multiple hazards (Muttarak and Lutz, 2014; Toya and Skidmore, 2015).

SM6.3.1.3.4 Transfer of risk/impacts to other areas/people: negative moderate (high agreement, medium evidence)

Disaster impact and recovery time are strongly influenced by the behaviour and actions of individuals, communities, businesses and government organisations (Aerts, 2018). Emergency planning and disaster management interventions for both slow-onset and sudden disasters may inadvertently shift hazard, exposure and vulnerability to other places and people, particularly if social and physical interconnectivities are not adequately accounted for; this is a particular concern in dense informal settlements where infrastructure is lacking, interconnectivities are highly complex and communities are often excluded from early-warning and evacuation systems (Thomas et al., 2019; Williams et al., 2019; Ziervogel et al., 2016).

SM6.3.1.3.5 Social capital: positive moderate (high agreement, medium evidence)

Emergency risk management structures and disaster reduction interventions can strengthen social capital directly and/or indirectly. For example, enhancing organisational capacities and social learning, strengthening communication and trust between actors across multiple scales through civic engagement for risk interventions and enabling access to risk related information through ICTs (Eakin et al., 2015; Magee et al., 2016; Marchezini et al., 2017; Narain et al., 2017; Haworth et al., 2018). Recent evidence also confirms the role of Indigenous knowledge and local knowledge in management practices to reduce climate risks through early-warning preparedness and response (see also Section 6.3.2.3). These practices are particularly important where alternative early-warning methods are absent. For instance, Abudu Kasei, Joshua and Benefor (2019) show that Indigenous knowledge gathered through observations on changes in natural indicators (such as links between rainfall patterns, certain flora and fauna, and temperature changes) could be applied to develop early warning of climate hazards (floods and droughts) in informal urban settlements in African countries such as Ghana.

SM6.3.1.3.6 *Livelihoods: positive moderate (high agreement, medium evidence)*

Livelihood opportunities can be enhanced through emergency management and security interventions (particularly when participatory or community led) such as through increased public awareness and emergency preparedness, capacity building through participatory early-warning systems or where relocation from hazard prone areas such as flood plains improves access to employment and other opportunities near urban centres (Lumbroso et al., 2016; Magee et al., 2016; Marchezini et al., 2017; Sarzynski, 2015).

SM6.3.1.3.7 *Health: positive moderate (high agreement, medium evidence)*

Emergency management planning and risk interventions, such as flood prevention measures, often have co-benefits for enhancing health and well-being through reducing exposure to communicable diseases associated with post-flood conditions (Matsuyama et al., 2020; Satterthwaite et al., 2019; Scovronick et al., 2015; Zerbo et al., 2020). Similarly, interventions to address disaster risk associated with drought such as increased access to piped water have important co-benefits for reducing water-borne and vector-borne diseases (Sena et al., 2017).

SM6.3.1.3.8 *Ecological: positive moderate (high agreement, medium evidence)*

Reducing disaster risk through nature-based solutions using green and blue infrastructure can have considerable co-benefits for strengthening ecosystem services such as flood protection via mangrove stands (McPhearson et al., 2018; Andersson et al., 2019; Frantzeskaki et al., 2019).

SM6.3.1.3.9 *Flexibility post-deployment: positive moderate (medium agreement, medium evidence)*

Disaster risk management systems face increasing challenges in adapting to evolving risk profiles, shaped by expanding urban areas and changing environmental conditions associated with climate change (Fraser et al., 2017). However, organisational structures of emergency management and interventions to support disaster risk reduction such as climate forecasting and early-warning systems are adaptable to new risks and evolving developmental conditions (Lumbroso et al., 2016; Marchezini et al., 2017). For example, insurance can be adjusted for new risks and evolving development contexts (Surminski and Thieken, 2017; Hanger et al., 2018)

SM6.3.1.3.10 *Deployable at scale: positive moderate (medium agreement, medium evidence)*

Emergency management initiatives such as integrated city services, early-warning systems and climate forecasting are often deployable at city scales and more widely (Zia and Wagner, 2015; Baklanov et al., 2018). However, often those that are most vulnerable and marginalised living in informal settlements do not benefit from integrated health, flood and other services, or receive warnings regarding hazardous events (Nissan et al., 2019).

SM6.3.1.3.11 *Benefit to other infrastructure systems adaptation: positive moderate (high agreement, medium evidence)*

Emergency management and disaster risk interventions such as flood barriers, fire protection and landslide prevention measures can help protect and enhance the resilience of diverse infrastructures, including green and blue infrastructure downstream (Matthews et al., 2015; Matos Silva and Costa 2016; Nolon, 2016; Mateos et al., 2020).

SM6.3.1.3.12 *Economic feasibility: positive small (high agreement, medium evidence)*

Climate change and disaster risk exacerbate existing problems of economic development, yet macro-economic planning seldom incorporates adaptation. When urban economic crises overlap with increased climate pressure and disaster risks, the impacts are likely experienced in the city region and beyond (Pelling et al., 2018). The link between urban disaster risk reduction (DRR), adaptation to climate change and macro-level trends of economic development requires further research and improved modes of communication to reach diverse city actors (Fankhauser and McDermott, 2016; World Bank, 2019). Disaster and emergency management funding is often lacking across government levels, particularly in low- and middle-income countries (Adelekan et al., 2015), thereby impeding comprehensive deployment of city-wide interventions such as built large-scale infrastructure flood control infrastructure.

SM6.3.1.3.13 *Mitigation co-benefit: positive moderate (high agreement, medium evidence)*

Reducing disaster risk using measures that protect and enhance green infrastructure such as mangrove swamps for flood regulation can have considerable mitigation co-benefits through enhancing air quality, carbon sequestration and supporting air temperature regulation (Carter et al., 2015; McPhearson et al., 2018; Andersson et al., 2019; Frantzeskaki et al., 2019). At the same time, there are concerns about the unintended consequences of investing in green infrastructure for nature-based solutions such as how it may contribute to gentrification (Haase et al., 2017; Anguelovski et al., 2018; Turkelboom, 2018).

SM6.3.1.3.14 *Targets reducing poverty and marginalisation: positive small (medium agreement, medium evidence)*

Exposure to health, flooding and drought risks of people living in slums is a growing concern, as is disaster preparedness and the ability to support the needs of vulnerable groups such as the elderly, children and disabled, where data is often lacking (Lilford et al., 2016; Castro et al., 2017). However, there are notable examples of low-income communities setting up their own disaster reduction interventions that can reduce marginalisation and poverty, such as community disaster insurance mechanisms (Archer, 2012). While community-led resilience agendas may tackle poverty-related issues, they may struggle to tackle city-wide structural forms of inequality (Chu, 2018).

SM6.3.1.3.15 Inclusive and locally accountable: positive small (medium agreement, medium evidence)

Disaster survivors and growing urban refugee populations are often displaced across the city, thereby complicating efforts to track and provide support (Maynard et al., 2017). Access to information is critical for adapting to climate risk and reducing vulnerability to hazards, yet access to this information is often not equally available (Ma et al., 2014). Community generated, assessed and led data gathering and interventions for risk reduction, particularly in informal settlements, helps develop deliberation spaces, communal solidarity and cohesion, and shared adaptation strategies, leading to increased agency and accountability (Sakijege et al., 2014; Allen et al., 2020; Visman et al., 2020).

SM6.3.1.3.16 Social transformation: positive moderate (medium agreement, medium evidence)

There are emerging examples of emergency management and disaster reduction interventions such as for hurricanes in Puerto Rico where the civic sector and community-based organisations and local residents are becoming active in disaster recovery and are now catalysing actions to advance social transformation and sustainable development (see Case Study 6.4). However, many political, governance, economic and other barriers remain. Through partnerships with NGOs and research institutions, informal settlement residents are increasingly leading mobilisation efforts to map community risks and develop community-led early-warning systems and emergency management interventions for flooding, disease outbreaks, fires and other risks (Sakijege et al., 2014; Allen et al., 2020; Osuteye et al., 2020; Visman et al., 2020). These initiatives have considerable social transformation potential but remain constrained by structural forms of power imbalances, inequality and governance challenges (Chu, 2018).

SM6.3.1.3.17 Ecological transformation: positive moderate (medium agreement, medium evidence)

Medium evidence from cities around the world such as the urban Regions of Stuttgart and Berlin in Germany (Larsen, 2015), Greater Manchester in the UK (Carter et al., 2015) and Colombo in Sri Lanka (Perera and Emmanuel, 2018) reveals that risk reduction through zoning and land use can effectively protect and expand green infrastructure and soft land cover to alleviate pluvial flooding and decrease the urban heat island (UHI) effect. However, such approaches are increasingly being criticised for their impacts on disadvantaged groups, and green infrastructure programmes are increasingly linked to gentrification impacts (Anguelovski et al., 2019). Furthermore, there is an action gap as green infrastructure plans often fail to deliver in practice (Zölch et al., 2018). Community-led interventions and incorporating Indigenous knowledge and traditions of nature management provide entry points for the sustainable management of resources, such as seed banks, urban agriculture and the local management of watersheds and floods (Chandra and Gaganis, 2016; Cid-Aguayo, 2016). Better policy support and mainstreaming of ecosystem-based adaptation will improve sustainable urban development.

SM6.3.1.4 Health Services (see Section 6.3.2.4)

SM6.3.1.4.1 Multiple climate hazards: positive moderate (high agreement, robust evidence)

Health services include primary, secondary and tertiary care, as well as public health (health protection measures, disease control) which are able to prevent or treat health issues caused by multiple climate hazards (e.g., Jay et al., 2020; Marcos-Marcos et al., 2018). Climate-resilient health systems are a vital part of adaptation to protect the most vulnerable from climate change (WHO 2020, Nuzzo et al., 2019). Health services focused on prevention (health protection and disease control) are most effective in reducing the impacts of climate hazards, but regions lack investment in public health compared with treatment services.

SM6.3.1.4.2 Systemic vulnerability reduction: positive moderate (high agreement, robust evidence)

Public health measures improve population health and increase household resilience to shocks. They reduce social vulnerability with relevance to climate related hazards and at least one more risk type (e.g., pandemic, pollutant, migration/displacement).

SM6.3.1.4.3 Reduces new hazard exposure generated: positive moderate (high agreement, medium evidence)

Public health measures are designed to reduce exposures to new and existing hazards (e.g., public health campaigns, vector control, reducing heat exposures). Behavioural change strategies need to be combined with other measures, such as improved housing design and spatial planning (Rydin et al., 2012).

SM6.3.1.4.4 Transfer of risk/impacts to other areas/people: negative negligible (high agreement, medium evidence)

Does not shift hazard, exposure, vulnerability or capacity to other places/people. Public good as interventions have wider benefits to the population than to the individual (e.g., herd immunity from vaccination).

SM6.3.1.4.5 Social capital: positive high (high agreement, medium evidence)

Builds trust and social capacity and communication. Health services are an important determinant of social capital. Supporting health is an investment in human capital and in economic growth; without good health, children are unable to go to school and adults are unable to go to work. Community workers can be involved in delivery of health services. Urban governments have the potential to work with a wide range of stakeholders to build strong intersectoral collaborations that will improve urban health (Rydin et al. 2012). In particular, public health partners should work more closely with urban planners. Local government adaptation planning is facilitated by information on health impacts (Riecken et al., 2015), highlighting the need for monitoring and surveillance as well as for local evidence-based risk assessments.

SM6.3.1.4.6 Livelihoods: positive small (high agreement, medium evidence)

Improved health will increase the capacity for work (formal and informal). A healthy population improves the economy, as demonstrated by the WHO Commission on Macro-Economics and Health (WHO 2001). The health sector is also a major employer and many countries do not have the level of coverage recommended by WHO. Investment in human resources for health not only strengthens the health system, but also generates local employment and contributes to economic growth (Karan et al., 2021).

SM6.3.1.4.7 Health: positive moderate (high agreement, robust evidence)

Universal health coverage (UHC) entails that all individuals in urban communities receive the health services they need without suffering financial hardship. UHC includes the full spectrum of essential, quality health services, from health promotion to prevention, treatment and rehabilitation, across the life course. *Robust evidence* exists of the benefits of these services to population health. In most countries, access to health services is better in urban areas, but there are still large urban populations with insufficient coverage of health services (WHO WB 2015). Such populations are vulnerable to climate and other hazards, and many families rely on out-of-pocket spending to cover health costs, and risk further poverty.

SM6.3.1.4.8 Ecological: nil (medium agreement, limited evidence)

Limited potential for ecosystem services within the formal health sector. There is potential to incorporate NBS within the hospital estate, particularly for cooling buildings and outdoor spaces, and to improve mental health and well-being (through contact with nature). There is a *limited evidence* base.

SM6.3.1.4.9 Flexibility post-deployment: nil (medium agreement, medium evidence)

Some flexibility post-deployment (public health services are very flexible) but buildings (health care infrastructure) have lock ins regarding building design and situation.

SM6.3.1.4.10 Deployable at scale: positive high (high agreement, robust evidence)

Health service measures are deployed at scale and should be targeted to the needs of the population. The effectiveness of single or programme-wide interventions has been observed at the city scale in a variety of contexts and for a range of diseases/hazards. There is also *robust evidence* of the cost effectiveness of health interventions, which are reviewed regularly and systematically, for example for the Disease Control Priorities Project (DCP3) (Black et al., 2016).

SM6.3.1.4.11 Benefit to other infrastructure systems adaptation: nil (medium agreement, medium evidence)

Health services are not generally connected to downstream infrastructure. However, health services are very reliant on upstream (critical) infrastructure (water, transport, energy and power).

SM6.3.1.4.12 Economic feasibility: positive small (medium agreement, medium evidence)

Universal health coverage is economically feasible but requires investment from national and local government. Countries must increase spending on primary health care by at least 1% of their gross domestic product (GDP) if the world is to meet the health targets agreed under the SDGs (WHO 2019).

SM6.3.1.4.13 Mitigation co-benefit: positive small (medium agreement, medium evidence)

The health sector is responsible for a significant proportion of carbon emissions. Health systems are beginning to address carbon reduction measures, and several hospital and health sector organisations have set emissions reduction targets: low carbon health care. The carbon footprint of the local or national health systems is determined by models of care and clinical behaviours, as well as by the buildings and technologies used.

SM6.3.1.4.14 Targets reducing poverty and marginalisation: positive moderate (high agreement, robust evidence)

Health policies often designed to reduce poverty and inequality. Universal health coverage has a main objective in reducing poverty and health and social inequalities. Ill health can be a cause of poverty, and poverty will cause ill health.

SM6.3.1.4.15 Inclusive and locally accountable: positive small (medium agreement, medium evidence)

High potential for transparency and local engagement in service design. Health services should be designed in collaboration with local partners. Community engagement is increasingly being incorporated into health service delivery, that is, the inclusion of local health system users and community resources in all aspects of design, planning, governance and delivery of health care services.

SM6.3.1.4.16 Social transformation: positive small (low agreement, limited evidence)

Potential for wider social benefits and re-organisation of public structures. UHC is a key part of addressing inequalities in urban areas. Public health has the potential to enable collaboration across sectors and facilitate transformational change.

SM6.3.1.4.17 Ecological transformation: nil (low agreement, limited evidence)

Some potential through health education. Training and education for health care professionals is beginning to consider including methods to address climate change and planetary health, as well as to increase awareness (Horton et al., 2014).

SM6.3.1.5 Education and Communication (see Section 6.3.2.5)

SM6.3.1.5.1 Multiple climate hazards: positive high (high agreement, medium evidence)

Since AR5, there has been significant growth in research about climate education and activism (O'Brien et al., 2018; Simpson et al., 2019; Hayward, 2021). Knowledge systems including formal educational provision (capital assets, syllabus and human capital), informal learning based in social interaction and customary institutions (including through social media) and public communication (news media, government and other information systems including commercial messaging) cover a range of hazards and influences risk and behaviour for more than one climate-associated hazard (O'Neill et al., 2020).

SM6.3.1.5.2 Systemic vulnerability reduction: positive moderate (medium agreement, medium evidence)

Given the amount of time that children spend in school settings, adapting educational infrastructure and programmes to climate change is highly important. This includes not only making physical structures safe, but also providing students with the knowledge and confidence to support individual and family-based adaptation (Napawan et al., 2017; Hayward, 2021). Several international non-governmental agencies (e.g., Plan International) and UN agencies (e.g., UNICEF and UNDRR) have prioritised safer schools and child-centred risk management that often focus on schools as places that should be prioritised for retrofitting and safe construction, but also as focal points for knowledge dissemination and community organising, where impacts can extend beyond the school to reduce risk amongst students' families (UNICEF, 2019).

SM6.3.1.5.3 Reduces new hazard exposure generated: positive moderate (medium agreement, medium evidence)

Access to knowledge and educational opportunities, as well as effective communication regarding climate change and related risks, are drivers of human behaviour and can help to reduce vulnerabilities to multiple hazards (O'Neill et al., 2020). Adapting educational infrastructure and programs to climate change includes making physical structures safe and also providing students with the knowledge and confidence to support individual and family-based adaptation (Napawan et al., 2017; Cutter-Mackenzie and Rousell, 2019; Hayward, 2021). Recent evidence also confirms the role of Indigenous knowledge and local knowledge in management practices to reduce climate risks through early-warning preparedness and response (Barau et al., 2015; Abudu Kasei et al., 2019; Hiwaski et al., 2015).

SM6.3.1.5.4 Transfer of risk/impacts to other areas/people: positive small (high agreement, medium evidence)

Several international non-governmental agencies (e.g., Plan International) and UN agencies (e.g., UNICEF and UNDRR) have prioritised safer schools and child-centred risk management that often focus on schools as places that should be prioritised for retrofitting and safe construction, but also as focal points for knowledge dissemination and community organising, where impacts can extend beyond the school to reduce risk amongst students' families (UNICEF, 2019).

SM6.3.1.5.5 Social capital: positive high (high agreement, robust evidence)

Climate change education has increasingly focused in urban settlements on enhancing children and young people's political agency in schools, universities and in formal and informal media settings (Cutter-Mackenzie and Rousell, 2019). Furthermore, incorporating Indigenous knowledge can identify people-oriented and place-specific scenarios leading to developing urban adaptation policies that foster identity, dignity, self-determination and better collective decision making/capacity to act (McShane, 2017; Preston, 2017).

SM6.3.1.5.6 Livelihoods: positive high (high agreement, medium evidence)

Access to knowledge is an important determinant of well-being, inclusivity and livelihood mobility, and for driving human behaviour (O'Brien et al., 2018; Simpson et al., 2019; Hayward, 2021). Individuals acquire knowledge, skills and competencies through education that can strengthen their adaptive capacity and livelihood opportunities (Muttarak and Lutz, 2014). Adapting educational infrastructure and programmes to climate change includes making physical structures safe through retrofitting and safe construction, but also providing students with the knowledge and confidence to support individual and family-based adaptation and child-centred risk management (O'Brien et al., 2018; O'Neill et al., 2020).

SM6.3.1.5.7 Health: positive high (high agreement, medium evidence)

Access to knowledge is an important determinant of well-being, inclusivity and livelihood mobility, and for driving human behaviour (O'Brien et al., 2018; Simpson et al., 2019; Hayward, 2021), which has direct implications for human health. Increasing educational levels of a population leads to a decrease in vulnerability and improves human development indicators, including health (O'Neill et al., 2020; Muttarak and Lutz, 2014).

SM6.3.1.5.8 Ecological: positive moderate (high agreement, limited evidence)

Climate education helps nurture environmental citizenship and activism (Paraskeva-Hadjichamb, 2020) and provides students with the knowledge and confidence to support individual and family-based adaptation and environmental protection benefits. Recent studies indicate the expanding role and relevance of Indigenous knowledge and education for ecological restoration and urban commons management (Nagendra, 2016; Nagendra and Mundoli, 2019).

SM6.3.1.5.9 Flexibility post-deployment: positive moderate (high agreement, medium evidence)

Education systems and communication strategies can be adapted and updated to include information on new risks and development conditions (Muttarak and Lutz, 2014; O'Neill et al., 2020).

SM6.3.1.5.10 Deployable at scale: positive small (medium agreement, limited evidence)

While public education programmes, including the use of school curricula and museums and public media raise awareness and sensitise populations on climate change impacts and the general need for adaptation (UNICEF, 2019; Paraskeva-Hadjichamb, 2020; O'Neill et al., 2020), there are limited examples of specific education and communication programmes designed as part of adaptation policy and little evidence of the outcomes associated with these interventions.

SM6.3.1.5.11 Benefit to other infrastructure systems adaptation: unknown (low agreement, limited evidence)

SM6.3.1.5.12 Economic feasibility: unknown (low agreement, limited evidence)

SM6.3.1.5.13 Mitigation co-benefit: positive moderate (high agreement, medium evidence)

Climate education and communication can have both adaptation and mitigation benefits (O'Neill et al., 2020; Muttarak and Lutz, 2014). Social movements on climate mitigation, such as the Transition Movement (Feola and Nunes, 2014), and school strikes may serve as an example for mobilisations more specifically about climate adaptation and the way new, networked, grassroots citizen activism and community organisations can encourage urban institutional change (Jordan et al., 2018; Gunningham, 2019; Wahlström et al., 2019).

SM6.3.1.5.14 Targets reducing poverty and marginalisation: negative negligible (medium agreement, medium evidence)

Access to education and communication is unequal within and across urban contexts, with poorer and marginalised populations often having limited access due to limited funds and opportunity to attend. There are also considerable gender gaps in school enrolment and literacy rates (Muttarak and Lutz, 2014).

SM6.3.1.5.15 Inclusive and locally accountable: positive small (medium agreement, medium evidence)

Access to education and communication is unequal within and across urban contexts, with poorer and marginalised populations often having limited access due to limited funds and opportunity to attend. Recent important research (Macintyre et al., 2018) highlights the need for new, innovative and transformative learning approaches to climate education from school age to adult education. Emphasis is on inclusivity in learning and recognising diverse perspectives across multiple levels and settings, from formal and informal education to wider social learning (Macintyre et al., 2018). Indigenous and traditional knowledge is often excluded from formal climate policy and education (Tengö et al., 2014; Hidalgo, 2019).

SM6.3.1.5.16 Social transformation: positive moderate (high agreement, medium evidence)

Since AR5, there has been significant growth in climate education, communication and activism, and research (O'Brien et al., 2018; Simpson et al., 2019; Hayward, 2021). Despite the inequalities across urban contexts, there is potential to catalyse actions for sustainable development, and progress towards both social and ecological transformation, particularly if innovative transformative approaches to climate education and communication continue to be rolled out and scaled up (Macintyre et al., 2018). The potential for building resilience to deliver adaptation, especially transformative adaptation, requires an articulation of collective visions of the future and the imagination of alternative urban futures (Glaas et al., 2018) through design and deliberate engagement with cultural artefacts, technologies and performances.

SM6.3.1.5.17 Ecological transformation: positive moderate (medium agreement, robust evidence)

Since AR5, there has been significant growth in climate education, communication and activism, and research (O'Brien et al., 2018; Simpson et al., 2019; Hayward, 2021). Despite the inequalities across urban contexts, there is potential to catalyse actions for sustainable development, and progress towards both social and ecological transformation, particularly if innovative transformative approaches to climate education and communication continue to be rolled out and scaled up (Macintyre et al., 2018).

SM6.3.1.6 Cultural Heritage/Institutions (see Section 6.3.3.6)

SM6.3.1.6.1 Multiple climate hazards: positive moderate (high agreement, medium evidence)

Tangible and intangible cultural heritage and institutions influence individual and community risk profiles and vulnerability to multiple climate hazards (Fatorić and Seekamp, 2018; Fatorić and Egberts, 2020).

SM6.3.1.6.2 Reduces systemic vulnerability: positive moderate (medium agreement, medium evidence)

Recent evidence highlights the role of intangible cultural heritage regarding Indigenous knowledge and local knowledge in management practices to reduce climate risks through early-warning preparedness and response (Barau et al., 2015; Abudu Kasei et al., 2019; Hiwaski et al., 2015), which can support physical and social vulnerability reduction, with co-benefits for reducing other risk types such as maintaining livelihoods and thereby avoiding economic shock.

SM6.3.1.6.3 Reduces new hazard exposure generated: positive moderate (medium agreement, limited evidence)

Indigenous or local knowledge is found to shape perceptions about climate change risk, its acceptable limits, causation and preferences for adaptation (see also Pyhälä et al., 2016 for a review; see Jaakkola et al., 2018 for impacts on Indigenous peoples in the EU). Local perceptions about climate change in turn shape adaptation behaviour in rural settlements and urban communities (Lee et al., 2015a; Larcom et al., 2019; Fatorić and Seekamp, 2018; Fatorić and Egberts, 2020). Adapting built cultural heritage to climate change includes making physical structures safer and can reduce vulnerability to multiple risks (Fatorić and Egberts, 2020; Cutter-Mackenzie and Rousell, 2019). Recent evidence also confirms the role of Indigenous knowledge and local knowledge in management practices to reduce climate risks through early-warning preparedness and response (Barau et al., 2015; Abudu Kasei et al., 2019; Hiwaski et al., 2015).

SM6.3.1.6.4 Transfer of risk: negative moderate (high agreement, medium evidence)

Human behaviour relating to built cultural heritage and institutions can create unintended risk transfers and reduce adaptive capacities, for example in the emergence of 'last chance tourism'(Lemieux et al., 2018) focused on built cultural heritage at risk from climate change-associated events including decay or even total loss generated by increased flooding and sea level rise (Camuffo et al., 2019, and water infiltration from post-flood standing water (Camuffo, 2019). Last chance tourism can lead to increased tourist interest over a short time horizon and to precarious economic conditions which can lead to further accelerated degradation of cultural heritage sites already at risk from climate change.

SM6.3.1.6.5 Social capital: positive high (medium agreement, medium evidence)

Learning about past societal and environment changes through heritage offers opportunity for reflection and the transfer of knowledge and skills (Jackson et al., 2018; Fatorić and Egberts, 2020). Incorporating intangible cultural heritage, Indigenous knowledge and values, into adaptation decision making can identify people-oriented and place-specific scenarios leading to developing urban adaptation policies that foster identity, dignity, self-determination and better collective decision making/capacity to act (McShane, 2017; Preston, 2017).

SM6.3.1.6.6 Livelihoods: positive moderate (medium agreement, robust evidence)

Indigenous knowledge, skills and competencies, as well as values, can strengthen adaptive capacities and create livelihood opportunities (Jackson et al., 2018; Fatorić and Egberts, 2020). For example, the Kalasha communities residing in the Hindu Kush mountain ranges of Pakistan employ ancestral meteorological and astronomical livelihood and knowledge systems called 'Suri Jagek', for predicting weather patterns and planning harvests, which can help support livelihoods and resilience under a changing climate (UNESCO, 2021). Adaptation of built cultural heritage can also provide livelihood opportunities for those whose employment is linked to the heritage site or building, especially if local resources (craftsmanship and materials compatible with the originals) are used (Phillips, 2015).

SM6.3.1.6.7 Health: positive moderate (high agreement, medium evidence)

Cultural heritage in the form of traditional technological, social and tangible infrastructural solutions for adaptation and mitigation can improve health and well-being in cities, if equity and justice aspects are accounted for (Anguelovski et al., 2016; Shi et al., 2016).

SM6.3.1.6.8 Ecological: positive moderate (medium agreement, limited evidence)

Adaptation of built cultural heritage at risk from climate change can have important co-benefits for surrounding and linked ecosystems in terms of preservation and strengthening resilience through increased protection measures (UNESCO, 2021). However, there is still limited literature on this.

SM6.3.1.6.9 Flexibility post-deployment: positive moderate (medium agreement, medium evidence)

Intangible cultural heritage in the form of Indigenous knowledge, traditions and values are constantly evolving and adapting to new development conditions and risks (Jackson et al., 2018; Fatorić and Egberts, 2020). Adaptation of built cultural heritage in the form of historical buildings, for example, has less flexibility for adapting to new risks, particularly sudden onset (UNESCO, 2021).

SM6.3.1.6.10 Deployable at scale: negative negligible (low agreement, limited evidence)

Individual projects that include local knowledge tend not to operate at scale. It would be possible to build programmes at scale (Allessa et al., 2015; UNICEF, 2019), but there is *limited evidence* of this and no formal assessments of impact on CRDPs were found.

SM6.3.1.6.11 Benefit to other infrastructure systems adaptation: positive small (medium agreement, limited evidence)

Adaptation of built cultural heritage, such as historic buildings, and sites such as the Cordilleras' Rice Terraces of the Philippines at risk from climate change can support resilience for both surrounding/linked green and blue infrastructure and ecosystem services through, for example, improved preservation and protection measures of the site and surrounding areas (UNESCO, 2021). However, there is still limited literature on this.

SM6.3.1.6.12 Economic feasibility: negative moderate (high agreement, medium evidence)

Last chance tourism can lead to increased tourist interest over a short time horizon and to precarious economic conditions, which can lead to further accelerated degradation of cultural heritage sites already at-risk from climate change (Lemieux et al., 2018). Financial constraints constitute the primary barrier hindering adaptation solutions, leading to no action at all, merely monitoring and documentation, or to annual maintenance (Fatoric and Seekamp, 2017; Fatorić and Egberts, 2020; Sesana et al., 2018; Xiao et al., 2019).

SM6.3.1.6.13 Mitigation co-benefits: positive small (medium agreement, limited evidence)

Accessing local resources (craftsmanship and materials compatible with the originals) improves built cultural heritage's adaptation capacity and has mitigation co-benefits through reduced carbon footprint (Phillips, 2015). Through intergenerational cumulative experience and oral narratives, locational histories and cultural practices, Indigenous knowledge and local knowledge can provide a historical perspective on changes in urban commons such as lakes and trees (Nagendra, 2016), as well as past climatic changes or climate baselines (Ajayi and Mafongoya, 2017).

SM6.3.1.6.14 Targets reducing poverty and marginalisation: positive moderate (medium agreement, limited evidence)

Urban decision making that includes Indigenous and local knowledge has co-benefits for addressing indigenous dispossession, historical inequities and marginalisation of indigenous values that occurred (see Orlove et al., 2014; Pearce et al., 2015; Maldonado et al., 2016; Carter, 2019; Parsons et al., 2019). Indigenous and local knowledge can help deliver culturally appropriate strategies and local choices for urban risk management through, for example, community-based observation networks (Alessa et al., 2016).

SM6.3.1.6.15 Inclusive and locally accountable: positive moderate (high agreement, medium evidence)

Intangible cultural heritage such as Indigenous and traditional knowledge has often been excluded from formal climate policy and education (Tengö et al., 2014; Hidalgo, 2019). However, since AR5 there has been increasing recognition of the contribution that understanding traditional coping strategies and Indigenous and local knowledge can make in urban adaptation planning and action (Nakashima et al., 2018; Abudu Kasei et al., 2019). Therefore, addressing traditional and local environmental knowledge can inform community-appropriate climate adaptation responses (Fernández-Llamazares et al., 2015). Urban decision making that includes Indigenous and local knowledge has co-benefits for addressing indigenous dispossession, historical inequities and marginalisation of indigenous values that occurred (see Orlove et al., 2014; Pearce et al., 2015; Maldonado et al., 2016; Carter, 2019; Parsons et al., 2019). However, regarding built cultural heritage, there are differences in who benefits from infrastructures, for example, as they are inherently political and embedded in social contexts, politics and cultural norms (McFarlane and Silver, 2017), which are not necessarily shared by all and can thus lead to tensions.

SM6.3.1.6.16 Social Transformation: positive moderate (high agreement, robust evidence)

The potential for building resilience to deliver adaptation, especially transformative adaptation, requires an articulation of collective visions of the future and the imagination of alternative urban futures (Glaas et al., 2018) through design and deliberate engagement with cultural artefacts, technologies and performances. Social movements can be powerful sources of such alternative visions of the future.

SM6.3.1.6.17 Ecological transformation: positive moderate (high agreement, robust evidence)

There is considerable potential for cultural heritage to contribute to ecological transformation. For example, through intergenerational cumulative experience and oral narratives, locational histories and cultural practices, Indigenous knowledge can provide a historical perspective on changes in urban commons such as lakes and trees (Nagendra, 2016), as well as past climatic changes or climate baselines (Ajayi and Mafongoya, 2017) and thus support ecological transformation when applied to policy and practice.

SM6.3.2 Nature-Based Solutions

SM6.3.2.1 Temperature Regulation (see Section 6.3.3.1)

SM6.3.2.1.1 Multiple climate hazards: positive moderate (high agreement, robust evidence)

Nature-based solutions (NBS) for temperature regulation in the form of urban trees and other green spaces can cool surface and near-surface temperatures by providing shade and increasing evaporative cooling. While the effect size of these interventions vary with local climate, area coverage and foliage type, evidence suggests the cooling potential of daytime air temperatures averages 1.6°C. For surface temperatures, cooling effects of NBS tends to be greater, 0.32–3.67°C, although some studies report surface cooling of > 10°C (Knight et al., 2021). NBS for temperature regulation can also provide risk reduction for other hazards including reducing concentrations of certain pollutants. For example, ozone generation in the troposphere occurs at higher rates at higher temperatures. In addition, trees have been shown to remove ozone from their surroundings, leading to lower concentrations under tree canopies, with studies attributing up to 4.9% of concentration reductions to them (Nowak et al., 2000; Sicard et al., 2018). However, studies also show that trees may increase concentrations of gaseous polycyclic aromatic hydrocarbons associated with combustion, even while reducing concentrations of other pollutants due to tree-induced turbulence (Wang et al., 2018; Yli-Pelkonen et al., 2018). While not as effective as grass and other NBS for runoff management, urban trees can significantly reduce surface runoff by as much as 62%, as demonstrated in Manchester, UK (Armson et al. 2013). In addition, tree root systems may better penetrate compact urban soils, increasing water infiltration by up to 27 times compared with unplanted compact soils (Bartens et al., 2008). The effectiveness of urban trees at improving infiltration may be highly impacted by tree pit design elements such as pit elevation, mulching and pit guarding (Elliott et al., 2018). Outdoor green space and parks may also slightly reduce indoor heat hazards, as a modelling study shows in Paris (Viguie et al., 2020).

SM6.3.2.1.2 Systemic vulnerability reduction: positive small (low agreement, medium evidence)

There is evidence supporting that both proximity and visitation of green spaces and parks improve mental health and reduce depression (Sturm and Cohen 2014; Min et al. 2017; Wood et al. 2017), providing some systemic vulnerability reduction. However, direct positive impacts on other drivers of vulnerability are understudied. Although trees may reduce certain pollutants, they may increase others. (Eisenman et al., 2019). Some species of trees produce allergens, and effects are exacerbated by air pollutants (Sedghy et al., 2018).

SM6.3.2.1.3 Reduces new hazard exposure generated: negative negligible (low agreement, limited evidence)

There is *limited evidence* on the impact that NBS for temperature regulation might have on changing behaviour or population locations that can lead to increases or decreases in risk through human behaviour change. There is also *limited evidence* that parks and other open space are the primary driver that may displace vulnerable populations to less desirable housing stock and neighbourhoods, though this is raised as an increasing concern in recent literature (Anguelovski et al., 2018). In the USA, low-income neighbourhoods are associated with higher surface temperatures (Voelkel et al., 2018), which in turn may increase heat hazard exposure in displaced populations, should displacement occur. However, there is wide agreement that investments in NBS can reduce local temperatures and thus reduce exposure to future heat hazards in the locations where NBS are implemented.

SM6.3.2.1.4 Transfer of risk: positive negligible (low agreement, limited evidence)

Depending on urban geometry and urban canyon street configuration, computational fluid dynamics simulations show that tree barriers that are too tall and dense may increase air pollutant concentrations downwind and within the tree canopy, even while reducing street-level temperatures (Hagler et al., 2012; Baldauf, 2017; Ghasemian et al., 2017). In addition, release of biogenic volatile organic compounds from large tree stands may lead to ozone production in other parts of a city (Bonn et al., 2016), even while reduced lower temperatures and surface-level solar radiation may reduce local ozone production.

SM6.3.2.1.5 Social capital: positive high (high agreement, medium evidence)

Evidence suggests that parks can play an important role in fostering socialisation among certain urban populations (Esther et al., 2017). In addition, studies indicate enhanced social cohesion and social ties among park visitors in urban settings (Peters et al., 2010; Kaźmierczak, 2013; Jennings and Bamkole, 2019).

SM6.3.2.1.6 Livelihoods: positive moderate (high agreement, medium evidence)

Parks may provide employment opportunities to residents for its maintenance (Neckel et al., 2020). A report from the National Recreation and Park Association and prepared by the Center for Regional Analysis at George Mason University found that local parks contributed USD 50 billion in labour income and contributed to over 1 million employees in the USA (National Recreation and Park Association, 2020). In a survey of 12 towns in South Africa, blue and green infrastructure was found to employ over 17,000 people with a total salary of USD 37 million (King and Shackleton, 2020).

SM6.3.2.1.7 Health: positive moderate (high agreement, medium evidence)

There is good evidence supporting that both proximity and visitation (access to) of urban green and blue spaces improves mental health (Sturm and Cohen, 2014; Min et al., 2017; Wood et al., 2017). There is some *limited evidence* that proximity to green space increases other health indicators. The benefits of greenspace to increased physical activity (a key cause of non-communicable diseases) is limited as other factors are needed (e.g., Smith et al., 2017).

SM6.3.2.1.8 Ecological: positive moderate (medium agreement, medium evidence)

There is evidence suggesting that trees in urban and residential areas in Latin American countries serve as a stopover for migratory birds (Amaya-Espinel and Hostetler, 2019). Studies also report that vegetated patches in urban areas have more bird species (Filloy et al., 2019). Bird abundance has also been linked to vegetation coverage in urban areas via satellite imagery (Leveau et al., 2018). Evidence also suggests that urban trees may facilitate the establishment of invasive insect communities, many of which are pests to local flora (Branco et al., 2019). However, urban trees have also been found to counteract the negative impacts of artificial lighting and abundance of impervious surfaces on night-time pollinator populations (e.g., moths) (Straka et al., 2021).

SM6.3.2.1.9 Flexibility post-deployment: positive high (medium agreement, limited evidence)

Investing in vegetation for cooling has been shown to provide other climate adaptation benefits, given multi-functionality of most NBS. For example, a recent study found that tree pit design characteristics are more important than several tree characteristics to determine its runoff infiltration potential (Elliott et al., 2018). Modification of tree pits may provide an avenue for improving runoff reduction in areas where flooding may become a persistent issue, providing modest flexibility to respond to other hazards beyond temperature regulation. Similarly, green roofs implemented for cooling can be important local sources of stormwater runoff regulation (Cook and Larsen, 2020). Overall, urban vegetation for cooling can often also absorb stormwater and air pollutants, as well as reduce urban flooding impacts (Keeler et al., 2019).

SM6.3.2.1.10 Deployable at scale: positive high (high agreement, medium evidence)

Campaigns have successfully been carried out in cities for mass planting of urban trees in New York (Campbell, 2014 and Campbell et al., 2014) and Beijing (Yao et al., 2019). Surveys of urban tree planting efforts have been recorded for 52 cities in the Northeast USA (Doroski et al., 2020), finding over 500,000 trees were planted between 2012 and 2017, demonstrating evidence to deploy NBS at scale.

SM6.3.2.1.11 Benefit to other infrastructure systems adaptation: positive small (medium agreement, medium evidence)

There is *medium* evidence that street trees may reduce energy demand for cooling in cities (Viguie et al., 2020). Green roofs may provide limited outdoor cooling and reduce demand-side energy for indoor cooling (Santamouris, 2014; Hirano et al., 2019). Certain tree species, however, may increase vulnerability of electric systems to wind gust-related power outages in areas with exposed power infrastructure such as power lines and transformers (Cerrai et al., 2019, 2020; D'Amico et al., 2019).

SM6.3.2.1.12 Economic feasibility: positive high (high agreement, medium evidence)

Large tree planting campaigns such as those in New York (Campbell, 2014) and Beijing (Yao et al., 2019) may show economic feasibility of trees as an NBS to temperature regulation. In the USA, urban parks are estimated to create over USD 166 billion in economic activity, while contributing USD 87 billion to the national GDP (National Recreation and Park Association, 2020). Green roofs decrease energy fluxes to building envelopes, reducing the need for cooling. Energy cost savings from a decreased need for cooling may offset retrofitting costs, especially when considering indirect added value such as noise insulation, heat reduction and stormwater retention (Feng and Hewage, 2018; Susca, 2019).

SM6.3.2.1.13 Mitigation co-benefit: positive moderate (high agreement, robust evidence)

Green roofs can reduce carbon dioxide emissions by reducing the building energy demand and the substrate's ability to sequester atmospheric carbon (Shafique et al., 2020). A review of modelling and experimental studies found that energy use reductions range between –7% and 70%, with the majority of reporting savings of 0–20% depending on season, roof insulation and plant type used. Meanwhile, carbon sequestration capacity ranged between 0.303 and 1.88 kg CO_2 m^{-2} yr^{-1}. However, this reduction is a small fraction of annual emissions related to traffic, which can reach over 300 kg CO_2 m^{-2} yr^{-1} in urban areas (Gately et al., 2015).

SM6.3.2.1.14 Targets reducing poverty and marginalisation: negative negligible (medium agreement, limited evidence)

NBS for temperature regulation may displace residents if it is part of drivers that may increase living costs near where they are implemented (Zheng and Kahn, 2013; Anguelovski et al., 2018; Goossens et al., 2020). However, this may not be an inherent feature of urban NBS, as studies show that focus on use of informal green spaces (Rupprecht and Byrne, 2017) and smaller parks can limit or even counteract green gentrification (Chen et al., 2021).

SM6.3.2.1.15 Inclusive and locally accountable: positive negligible (medium agreement, limited evidence)

Although recent trends in participatory budgeting and planning seek to make governance and implementation more inclusive and accountable to local communities, as worldwide examples show (Kozová et al., 2018; Pogačar et al., 2020; Schneider and Busse, 2019), there is *limited evidence* that this approach is inherent to NBS for temperature regulation.

SM6.3.2.1.16 Social transformation: unknown (low agreement, limited evidence)

Historical data in many cities show increasing property values near urban parks and other green infrastructures. An example in Washington, DC, USA, attributed a 5% premium to homes within 500 ft (152.4 m) of parks (Harnik and Crompton, 2014), while street trees in Perth, Australia, were found to increase property value by close to AUD 17,000 (Pandit et al., 2013). These wealth increases may shift social power to property owners over time, potentially increasing inequality in urban decision making.

SM6.3.2.1.17 Ecological transformation: positive high (high agreement, medium evidence)

Studies suggest that urban vegetation leads to higher abundance of animal life and biodiversity. A study of insect species and urban vegetation in six cities in Switzerland found increased abundance and diversity of most measured species (Turrini and Knop, 2015), while a study in Melbourne, Australia, found that increasing vegetation from 10% to 30% increased occupancy of bats, birds, bees, beetles and bugs by up to 130% (Threlfall et al., 2017), with a particularly high impact on native species.

SM6.3.2.2 Air Quality Regulation (see Section 6.3.3.2)

SM6.3.2.2.1 Multiple climate hazards: positive moderate (high agreement, medium evidence)

Trees and green infrastructure have been shown to improve air quality through pollution removal by intercepting airborne particles (Nowak et al., 2006). Trees also absorb air pollution by uptake via leaf stomata, then gases diffuse into intercellular spaces and may be absorbed by water films to form acids (Nowak et al., 2006; Smith, 2012). For example, Matos et al. (2019) found that in Lisbon, Portugal, the best gains in air quality improvement have been obtained by improving the smallest green spaces, rather than investing in the largest green spaces. NBS for air quality regulation can also help to mitigate flooding, as air pollutants such as fine particulates impact precipitation and regional circulation patterns (Fiore et al., 2015), and urban trees can increase the runoff infiltration rates during rainfall inundation (Bartens et al., 2008). NBS for air pollution may also provide temperature regulation as some pollutants increase warming by trapping heat in the atmosphere (Arneth et al., 2009).

SM6.3.2.2.2 Systemic vulnerability reduction: positive small (medium agreement, limited evidence)

NBS for air quality regulation can mitigate air pollutants (Janhäll, 2015; Keeler et al., 2019), flooding (Fiore et al., 2015) and temperature (Arneth et al., 2009) by reducing pollutants that impact human health, a fundamental component of climate vulnerability. For example, planting trees along streets or in urban forests can reduce particulate matter, the ambient air pollutant with the largest global health burden (Tiwary et al., 2008; Janhäll, 2015; McDonald et al., 2016). Positive health impacts are assessed as a key contribution to systemic vulnerability reduction.

SM6.3.2.2.3 Reduces new hazard exposure generated: positive small (medium agreement, limited evidence)

There is *limited evidence* that documents behaviour or other social changes associated with NBS for air pollution, yet NBS can impact health, with implications for reductions in new hazard exposure. NBS can reduce multiple air pollutants (Matos et al., 2019) which have long-term potential benefits for both climate change and people-impacting new hazard exposure. Air pollutants such as light-absorbing particulate black carbon, light-scattering particulate sulphates, nitrates, organics and ozone are pollutants that impact human health as well as climate-forcing factors (Maione et al., 2016; Shindell et al., 2012) that may reduce hazard exposure. For example, Shindell et al. (2012) found that a reduction in methane and black carbon emissions can reduce projected global mean warming ~0.5°C by 2050, avoid 0.7–4.7 million annual premature deaths from air pollution and increases annual crop yields by 30–135 million metric tons in 2030 and beyond.

SM6.3.2.2.4 Transfer of risk: positive small (low agreement, limited evidence)

Air pollutants can be transferred from one place to another, mainly by wind (Gurumoorthy et al., 2021; Kim et al., 2015). The typical wind speed varies temporarily and spatially on a topographical basis (Gurumoorthy et al., 2021). Overall, there is little evidence that reducing air pollutants via the use of NBS in a specific area can lead to the transfer of the same risks or impacts to other areas. However, some tree species planted for air pollution reduction that are pollen producing may create other health risks, especially for allergy sufferers. Therefore, researchers caution practitioners to avoid planting trees as NBS for air pollution removal that are known to produce pollen problematic for allergy sufferers (Sedghy et al., 2018).

SM6.3.2.2.5 Social capital: positive moderate (high agreement, medium evidence)

NBS can encourage social capital through forms of economic empowerment and improving human–nature interactions (Welden et al., 2021) and increases in social capital may also be associated with less air pollution (Smiley, 2020). For example, Tidball et al. (2018) show how through community-based reforestation, in the case of New Orleans, Louisiana, USA, the act of planting trees strengthens social interaction and places for social engagement.

SM6.3.2.2.6 Livelihoods: positive small (medium agreement, medium evidence)

Along with reducing air pollution, NBS can create jobs for residents to run and maintain green and blue infrastructure (King and Shackleton, 2020). There is a moderate agreement that a reduction in air pollution can also save significant medical expenditure on diseases that are caused by air pollution such as chronic obstructive pulmonary disease, asthma and lung cancer (Jiang et al., 2016). For example, Xue et al. (2021) found that the PM2.5 reduction between 2013 and 2017 in China was associated with a saving of approximately USD 111 billion yr^{-1} nationally.

SM6.3.2.2.7 Health: positive moderate (high agreement, medium evidence)

There is a *high agreement* on the devastating direct impacts of air pollution on human health (Hewitt et al., 2020; Klompmaker et al., 2021; Tahara et al., 2021; Zhang et al., 2021) and the indirect impacts of air pollution by increasing the global warming (Arneth et al., 2009; Khalaila et al., 2021; Klompmaker et al., 2021). There is evidence that NBS, particularly through planting trees and green infrastructure, may reduce local exposure to air pollution and modify impacts of long-term exposure to air pollution (Crouse et al., 2019; Kim et al., 2019, pp. 2008–2016; Kioumourtzoglou et al., 2016). For example, Crouse et al. (2019) found that exposure to air pollution had a lower impact on the risk of dying in greener areas between non-immigrant Canadian adults.

SM6.3.2.2.8 Ecological: positive moderate (medium agreement, medium evidence)

Air pollution can pollute water and soil, which can kill crops and young trees (National Geographic Society, 2011). Exposure to volatile organic compounds of air pollutants is associated with an upregulation of intracellular antioxidants, resulting in an increased production of reactive oxygen species which is known to influence cancer development in the wild population (North et al., 2017; Sepp et al., 2019). Some air pollutants such as benzene, kerosene, toluene and xylenes have been found to be associated with mammary carcinomas in rodents (Huff et al., 1989; Maltoni et al., 1997). NBS that improve air quality have potential to benefit ecosystems primarily through pollution reduction, with benefits across ecological communities.

SM6.3.2.2.9 Flexibility post-deployment: positive high (high agreement, medium evidence)

There is *high agreement* that NBS for air quality such as planting trees and increasing green spaces can provide benefits other than absorbing air pollutants. Trees and green space can reduce outdoor and indoor heat hazards (Arneth et al., 2009; Viguié et al., 2020). Green infrastructure can also mitigate flood risk and exposure by reducing peak flows and surface runoff (Moore et al., 2016; Zhou, 2014), even when planted expressly for air quality benefits. For example, Bartens et al. (2008) found that tree root systems can increase water infiltration rate by up to 27-fold compared with unplanted soils and thus be adapted for stormwater regulation.

SM6.3.2.2.10 Deployable at scale: positive moderate (medium agreement, medium evidence)

Tree planting campaigns and programmes are being implemented at a city scale, such as many US cities including New York, Los Angeles and Chicago (Campbell et al., 2014; Pincetl et al., 2013) and at the regional scale, such as regions in China including Inner Mongolia, Ningxia and Gansu provinces (Xiao and Xiao, 2019). Furthermore, many cities run land acquisition programmes for urban open and green spaces and have successfully added new lands to their open and urban green spaces. For example, Portland City has added 1640 acres to the urban park system since 2001 (City of Portland, 2021). Similarly, the City of Sammamish in the USA has added 645 acres to its urban park system between 1999 and 2020 through the land acquisition program. How scalable tree planting and other green infrastructure interventions are in other Global South areas remains understudied.

SM6.3.2.2.11 Benefit to other infrastructure systems adaptation: positive small (medium agreement, limited evidence)

NBS is also important for urban drainage systems by slowing runoff rate and reducing the pressure on drainage systems, as well as lowering maintenance costs (Locatelli et al., 2020; Zhou et al., 2012). A limited number of studies show that trees and green areas for air quality regulation can reduce air temperature (Arneth et al., 2009; Viguié et al., 2020) and therefore can reduce energy demand for heating in buildings.

SM6.3.2.2.12 Economic feasibility: positive small (medium agreement, medium evidence)

Generally, investments in NBS are difficult to value (Vandermeulen et al., 2011) and a limited number of studies explored the economic feasibility of NBS. NBS investments can also create jobs for residents to plant, run and maintain green and blue infrastructure (King and Shackleton, 2020). A reduction in air pollution can save significant medical expenditure on diseases that are caused by air pollution (Jiang et al., 2016). Green spaces can also reduce outdoor and indoor temperature and reduce the cost of energy required for space cooling (Arneth et al., 2009; Viguié et al., 2020).

SM6.3.2.2.13 Mitigation co-benefit: positive moderate (high agreement, medium evidence)

Green NBS such as green spaces and trees can act as a carbon storage by absorbing CO_2 and reducing CO_2 emissions from power plants resulting in a reduction in cooling costs (Strohbach et al., 2012; Zhang et al., 2014). For example, Strohbach et al. (2012) found that the estimated average storage of CO_2 in tree biomass after 50 years ranges from 170 to 28 $MgCO_2$ ha–1 for an area of 2.16 ha that contains 461 different trees in Leipzig, Germany. The variation in the storage of CO_2 mainly depends on tree growth and tree mortality but remains a small fraction of urban carbon emissions.

SM6.3.2.2.14 Targets reducing poverty and marginalisation: Unknown (low agreement, limited evidence)

There is *limited evidence* for NBS interventions for reducing poverty and marginalisation as most studies have typically not taken account the multi-functional nature of NBS. Some studies have found an association between air pollution levels and socioeconomic status (Colmer et al., 2020; Kravitz-Wirtz et al., 2016; Neier, 2021), but this association cannot easily be fully explained by individual-, household- or metropolitan-level factors (Kravitz-Wirtz et al., 2016), challenging certainty about direct, local impacts of air pollution removal on income, medical bills or other economic impacts.

SM6.3.2.2.15 Inclusive and locally accountable: positive small (medium agreement, limited evidence)

There is some supported evidence that NBS for air quality benefits can improve inclusion and local accountability. Tidball et al. (2018) found that a community-based reforestation programme in New Orleans, Louisiana, USA, strengthened social interaction and places for social engagement. In Christchurch, New Zealand, 75% of urban trees are found on private land, suggesting that benefits of the urban forest include management by tens of thousands of individuals (Guo et al., 2019).

SM6.3.2.2.16 Social transformation: unknown (low agreement, limited evidence)

There is supportive evidence that NBS can encourage inclusion and community engagement (Tidball et al., 2018). However, there is also evidence that NBS, especially through green infrastructure investments, can lead to increased housing prices (Breunig et al., 2019; Harnik and Crompton, 2014) which may force low-income tenants to relocate and reinforce social segregation over time.

SM6.3.2.2.17 Ecological transformation: positive high (medium agreement, limited evidence)

NBS such as planting trees for air regulation can improve air quality and reduce pollution in water and soil (National Geographic Society, 2011), which provides ecological benefits while also improving animal health (Huff et al., 1989; Maltoni et al., 1997). Studies suggest that urban vegetation that provides NBS can lead to higher abundance of animal life and biodiversity. A study of insect species and urban vegetation in six cities in Switzerland found increased abundance and diversity of most measured species (Turrini and Knop, 2015), while a study in Melbourne, Australia, found that increasing vegetation from 10% to 30% increased occupancy of bats, birds, bees, beetles and bugs by up to 130% (Threlfall et al., 2017), with particularly high impact on native species. However, some studies have also found that large-scale tree planting programmes target many ecosystems that do not naturally support dense tree cover (Fleischman et al., 2020; Veldman et al., 2019), which may destroy the habitats of plants and animals adapted to open ecosystems (Fleischman et al., 2020).

SM6.3.2.3 Stormwater Regulation and Sanitation (see Section 6.3.3.3)

SM6.3.2.3.1 Multiple climate hazards: positive small (high agreement, medium evidence)

NBS for stormwater regulation can mitigate flood risk and exposure to pollutants by reducing peak flows and total surface runoff (Moore et al, 2016; Zhou, 2014) and thus has potential to provide multiple benefits for risk reduction. Prioritising one or another stormwater-related challenge may impact key siting and design choices, limiting the intervention's capacity to deliver both benefits simultaneously unless explicitly intended (McPhillips et al., 2020). NBS are multi-functional, so investments for stormwater reduction can also provide temperature regulation. However, specific choices in vegetation that can increase, for example, cooling, may be overlooked if stormwater regulation is the only targeted benefit during implementation (Hoover et al., 2021.). For example, in the city of Philadelphia, USA, most green infrastructure interventions for stormwater management are non-vegetated, such as permeable pavement (Spahr et al., 2020).

SM6.3.2.3.2 Systemic vulnerability reduction: positive small (medium agreement, medium evidence)

NBS for stormwater regulation and sanitation can enable access to recreation (Keeler et al., 2015) and increase property values when water usability is improved (Artell, 2014) or a change in flood risk is perceived (Kim et al., 2020). In general, the evidence on the impact of green infrastructure for NBS on property values is mixed, but relatively positive in the Global North (Venkataramanan et al., 2019). In the Global South, proximity to green spaces has been observed to be linked to lower property values due to differing effects on sense of safety and security (Cilliers et al., 2013). Greening in historically disenfranchised or disinvested neighbourhoods has been linked to gentrification (Anguelovski et al., 2018) and injustices due to misrepresentation in the decision making processes that lead to greening (Turkelboom, 2018).

SM6.3.2.3.3 Reduces new hazard exposure generated: positive small (medium agreement, limited evidence)

There is *limited evidence* on the impact that NBS for stormwater might have on changing behaviour or population locations that can lead to risk reduction through human behaviour change. A case study in Hong Kong indicated that the presence of green infrastructure for stormwater regulation increases the price of apartments located on the first floor of apartment buildings (Kim et al., 2020). This observation suggests that a change in risk perceptions might encourage development in areas that benefit from green infrastructure, but the evidence is insufficient so far to support broad claims. However, there is wide agreement that investments in NBS can reduce peak flows in stormwater and reduce new local flood hazard exposure.

SM6.3.2.3.4 Transfer of risk: negative moderate (high agreement, medium evidence)

Traditional grey interventions may impact the social and ecological integrity of urban systems and create system lock ins (Depietri and McPhearson, 2017). In addition, grey infrastructure may cause adverse effects downstream by rapidly concentrating flow and pollutants in discharge points (Boot et al., 2016). Instead, green infrastructure and other NBS aim to improve stormwater management on site in a decentralised manner and reduce local and downstream risks (Dhakal and Chevalier, 2017). In case of improper management, NBS may contribute to the release of organic matter and/or nutrients, which may cause eutrophication in receiving water bodies (Janke et al., 2017; Ardón et al., 2010; Bierman et al., 2010).

SM6.3.2.3.5 Social capital: positive small (medium agreement, medium evidence)

The implementation process for NBS can contribute to improving local social capital when procedural justice is a component. NBS for stormwater regulation such as green infrastructure may face the pushback of local communities due to fears of gentrification (Wolch et al., 2014) or a perception about having a poorer performance than grey interventions (Dhakal and Chevalier, 2017; Thorne et al., 2018). For NBS for stormwater regulation and sanitation to be accepted and implemented, fostering social capital (Barclay and Klotz, 2019; Dhakal and Chevalier, 2017), including communities in the planning process from the very beginning (Hoover et al., 2021) and prioritising engaging with communities willing to accept green infrastructure (Hoover et al., 2021), have been described as critical needs. Once deployed, NBS for stormwater management can foster social cohesion (Hamann et al., 2020), in line with studies focused on the social benefits provided by green spaces such as parks or green roofs (Mesimäki et al., 2017; Markevych et al., 2017; Kaźmierczak, 2013).

SM6.3.2.3.6 Livelihoods: positive moderate (medium agreement, limited evidence)

There is *limited evidence* on the impact that green infrastructure for stormwater management has on livelihoods and well-being, with most studies focusing on shifting property value (Venkataramanan et al., 2019). Some case studies suggest that green infrastructure for stormwater management can reduce crime (Burkley et al., 2018; Kondo et al., 2015a) and generate significant employment when deployed at scale (King and Shackleton, 2020). Large green spaces that may provide stormwater mitigation benefits, even if not originally designed for this purpose, have shown positive impacts such as crime reduction, health improvement and pro-social behaviours (McKinney and VerBerkmoes, 2020), but these studies focus on larger, unmanaged green spaces, rather than engineered green infrastructure for stormwater management.

SM6.3.2.3.7 Health: positive moderate (medium agreement, limited evidence)

By improving water quality, NBS can reduce exposure to pollutants for people, ecosystems and animals. However, the evidence on the impact of NBS interventions on human health is limited, and further research is needed (Venkataramanan et al., 2019). Some types of interventions such as street trees or parks have been researched more broadly and their impacts on physical and mental health are widely recognised as positive, while newer types of interventions such as rain gardens, bioswales or green roofs have only begun to be studied (Suppakittpaisarn et al., 2017). Specific case studies have reported positive impacts of green roofs on mental health and the workplace (Lee et al., 2015b; Loder, 2014). Large green spaces that may provide stormwater mitigation benefits, even if not being strictly designed for this purpose, have shown positive health impacts (WHO, 2017).

SM6.3.2.3.8 Ecological: positive moderate (high agreement, medium evidence)

NBS for stormwater regulation can have a positive impact on ecosystems by improving the water quality of water bodies (Pennino et al., 2016). The value of this service depends on the characteristics of local built water infrastructure, such as presence of sewers, type (combined or separated), age, maintenance or impervious cover (Utz et al., 2016; Wollheim et al., 2015; LeFevre et al., 2015; Kaushal et al., 2014). The use of a combination of different NBS measures provides better results than single-type, isolated interventions (Chen et al., 2019). While the benefits of NBS are known at small scales, there is a lack of knowledge about the impact that urban NBS for stormwater management can have at larger scales such as catchment level (Golden and Hoghooghi, 2018).

SM6.3.2.3.9 Flexibility post-deployment: positive moderate (medium agreement, medium evidence)

NBS are considered to have medium to high flexibility (Ferreira et al., 2021; Hobbie and Grimm, 2020; Depietri and McPhearson, 2017) and to be better at avoiding lock ins and path dependencies than grey alternatives, while providing multiple benefits beyond stormwater (Depietri and McPhearson, 2017). Hybrid infrastructure systems (combining grey and green) designed under the safe-to-fail paradigm can provide more flexible and reliable solutions and are encouraged (Kim et al., 2019; Mei et al., 2018; Depietri and McPhearson, 2017; Grimm et al., 2015). NBS designed to support a wider range of co-benefits may be more adaptable to shift their focus to other hazards (e.g., increasing tree cover in large green spaces to increase shading and reduce heat). There is, however, a lack of post-development evidence on the performance of NBS, and most literature describes potential benefits.

SM6.3.2.3.10 Deployable at scale: positive moderate (medium agreement, limited evidence)

Modelling studies suggest that a catchment-wide implementation of small interventions can provide flood-risk reduction benefits (Webber et al., 2020). Several cities have developed GI at scale and/or have developed city-wide plans that identify priority areas of intervention (Hoover et al., 2021; Hopkins et al., 2018). The need to combine public with private property investments to bypass the space limitations in compact cities (Ferreira et al., 2021; Hoobie et al., 2020; Garcia-Cueva et al., 2018) is considered a key challenge in city-wide GI development. However, there is *limited evidence* regarding the impact of NBS at large spatial and temporal scales due the absence of data or efforts capturing large-scale NBS performance (Garcia-Cueva et al., 2018; Golden and Hoghooghi, 2018).

SM6.3.2.3.11 Benefit to other infrastructure systems adaptation: positive moderate (high agreement, medium evidence)

Mitigating urban flood risk can positively impact other urban infrastructure systems. For example, reducing flooding on roads reduces the impact of flooding events on traffic flows (Pregnolato et al., 2016). Green roofs have a longer life than conventional roofs and can protect them from radiation, wind and thermal fluctuations (William et al., 2016). By reducing peak flows into combined sewer systems, NBS also allow for the proper functioning of drainage systems without triggering combined sewer overflow (CSO) discharges (Pennino et al., 2016).

SM6.3.2.3.12 Economic feasibility: positive moderate (high agreement, medium evidence)

The assessed cost effectiveness of NBS for stormwater regulation varies depending on local contexts and whether co-benefits (Teotónio et al., 2021; Bixler et al., 2020; Eckart et al., 2018) and disservices (Hobbie and Grimm, 2020) are also included in the assessments. Case studies assessing more than one NBS type are limited (Bixler et al., 2020), and usually fail to incorporate several co-benefits owing to the complexity and lack of deeper knowledge on how to evaluate them (Teotónio et al., 2021). Nevertheless, there is increasing evidence that NBS for stormwater is cost-effective (sometimes more than traditional, grey approaches) (Bixler et al., 2020; Kozak et al., 2020; Mguni et al., 2016), especially in cities facing a need to update current infrastructures (Keeler et al., 2019). For instance, a 2010 study determined that a hybrid green–grey approach to stormwater management in New York City (NY, USA) was more cost-effective than a completely grey one (New York City Department of Environmental Protection, 2010).

SM6.3.2.3.13 Mitigation co-benefit: positive moderate (high agreement, medium evidence)

Vegetated NBS such as street trees may account for climate mitigation co-benefits (by capturing carbon). However, the principal way in which green infrastructure may contribute to GHG emission reductions is by replacing grey interventions, which show higher emissions due to the materials used and the emissions that take place during their installation and operation (Rasul and Arutla, 2020; Liu et al., 2020; Brudler et al., 2016; Spatari and Montalto, 2011).

SM6.3.2.3.14 Targets reducing poverty and marginalisation: positive small (medium agreement, limited evidence)

While NBS for stormwater management focuses on mitigating combined sewer overflows (CSOs) and urban flood risk, reducing CSOs may be the most common driver for siting and design criteria (Hoover et al., 2021; McPhillips et al., 2020). The use of technical indicators such as impervious surface or CSO areas (Heck, 2021; Meerow, 2020; Finewood et al., 2019) tends to lead to the prioritisation of areas that face other challenges such as air quality and heat, and that might be inhabited by vulnerable communities (Meerow, 2020). Cities investing in green infrastructure may develop parallel programs to improve access to income and alleviate poverty. For example, New York City's Million Trees NYC project to plant a million trees in the city also implemented a green jobs training programme that combined traditional workforce development to create jobs with teaching and environmental awareness raising (Falxa-Raymond et al., 2013).

SM6.3.2.3.15 Inclusive and locally accountable: positive negligible (medium agreement, limited evidence)

There is wide agreement that inclusion and local accountability are critical for improving participation in NBS planning and implementation. However, there is *limited evidence* that inclusive processes are commonly included. Participatory processes are necessary to ensure that NBS deployment considers the needs, preferences and concerns of affected residents and stakeholders (Wolch et al., 2014). Procedurally, just participatory processes have been described as lacking, although needed to ensure that the people included in the planning for NBS are representative of the population, avoiding racial and socioeconomic bias (Hoover et al., 2021; Verheij and Nunes, 2021; Wang and Palazzo, 2021). Environmental justice frameworks and models of inclusive governance have been proposed to support the further implementation of environmental justice dimensions during planning processes (Tozer et al., 2020; Meenar et al., 2018), as well as the potential benefits of relying on university–community partnerships to manage engagement (Gerlak and Zuniga-Teran, 2020).

SM6.3.2.3.16 Social transformation: unknown (low agreement, limited evidence)

There is little evidence about the capacity that NBS for stormwater management might have to substantially transform socioeconomic, legal or cultural systems. Given their relatively small scale of implementation, their impact may be expected to be low, if not null. The shift in some Global North cities towards managing stormwater through NBS and hybrid green–grey approaches has been observed to require innovative, holistic and flexible planning processes that promote cross-sectoral collaborations (Kvamsås, 2021). At a broad level (beyond stormwater-focused NBS), the tendency to focus on measurable benefits, cost-effectiveness and growth may lead NBS to contribute to perpetuating a neoliberal status quo (Kotsila, 2021). In the Global North, governance discourses around greening have been linked to increasing investment and a consequent increase in the costs of living (Garcia-Lamarca et al., 2021; Tozer et al., 2020). There is less conclusive evidence from Global South cases.

SM6.3.2.3.17 Ecological transformation: positive moderate (medium agreement, medium evidence)

By reducing CSOs (Moore et al., 2016; Zhou, 2014), NBS for stormwater management is able to improve the ecological integrity of receiving water bodies. For instance, a green infrastructure programme in Syracuse, NY, USA, led to significant improvements in the water quality of Lake Onondaga, positively impacting the lake's biodiversity (Flynn and Davidson, 2017). Less significant results, albeit positive, have been observed in Baltimore (Reisinger et al., 2019), as well as other empirical, experimental studies (Yang and Li, 2013). Besides their impact on downstream water bodies, vegetated NBS for stormwater management can have positive impacts on urban biodiversity (Nakamura et al., 2020), especially when multi-trophic, landscape-level relationships are considered (Filazzola et al., 2019), Improper maintenance, on the other hand, may lead to reductions in biodiversity if certain species outcompete others (Winfrey et al., 2018).

SM6.3.2.4 Coastal Flood Protection (Section 6.3.3.4)

SM6.3.2.4.1 Multiple climate hazards: positive moderate (high agreement, medium evidence)

Nature-based solutions (NBS) protect coasts from flooding through reducing the wave energy by drag friction, reducing wave overtopping by eliminating vertical barriers and absorbing floodwaters in soil (The Horinko Group, 2015; Arkema et al., 2017; Dasgupta et al., 2019; Zhu et al., 2020). There is also evidence that coastal green infrastructure protects coastlines from erosion through reducing wave transmission, increasing soil elevation through vertical accretion and binding soil properties (Bryant et al., 2017; Silva et al., 2016). Models for understanding where NBS may have more or less impact are also being developed at global scales (Conger and Chang., 2019; Menéndez et al., 2018; Guannel et al., 2016; Ruckelshaus et al., 2020).

SM6.3.2.4.2 Systemic vulnerability reduction: positive small (medium agreement, medium evidence)

There is *high agreement* that NBS can mitigate the effects of diverse challenges by enhancing sustainable urbanisation, restoring degraded ecosystems, developing climate change adaptation and mitigation, and improving environmental risk management (Lafortezz et al., 2018; Raymond et al., 2017; Restore America's Esturaries, 2016). Yet the extent of reduction in physical and social vulnerability through NBS depends on the NBS typology and geomorphology, as well as the degree of vulnerability and biodiversity (Veettil et al., 2021). For instance, there is some evidence that mangrove restoration of even small areas (a few m^2) can be effective in providing protective services for coastal populations (Soanes et al., 2021) and that calculating the ancillary vulnerability reductions from mangrove protection is crucial for national policy (Menéndez et al., 2018). At the same time, the distribution of vegetation cover and NBS is uneven, leading to socially uneven enjoyment of flood vulnerability reduction (Machado et al., 2019) or other impacts on income or health that may constitute more systemic vulnerability impacts.

SM6.3.2.4.3 Reduces new hazard exposure generated: positive moderate (high agreement, limited evidence)

There is *high agreement* that socio-cultural valuations of urban GI for climate adaptation can increase people's understanding of flooding risks and impacts (Derkzen et al., 2017), however empirical evidence from NBS for flood protection is scant. Evidence focuses on the perceptions of coral reef benefits and conservation (Imamura et al., 2020; Yamashita et al., 2021), as well as kelp forest restoration (Hynes et al., 2021), while studies point to the need for baselines that understand human responses to complex socio-ecological changes in coral reefs (Hoegh-Guldberg et al., 2019).

SM6.3.2.4.4 Transfer of risk: negative negligible (low agreement, limited evidence)

There is very little agreement and evidence that mangrove, kelp forest and coral reef restoration can lead to other risks or impacts to nearby areas or people. Studies are emerging to understand the impact of bamboo structures to create habitat for mangrove colonisation on wave reduction (Gijón et al., 2021), but more research is needed.

SM6.3.2.4.5 Social capital: positive moderate (medium agreement, limited evidence)

There is broad agreement that co-production of knowledge between stakeholders can foster democratic governance of NBS (Frantzeskaki et al., 2019; Vollstedt et al., 2021). The empirical evidence, however, is largely built on NBS for stormwater reduction and less so for flood protection. Existing evidence of social capital enhancement through NBS for flood protection alone is weaker (Venkataramanan et al., 2019). There is general agreement that to build social capital, NBS should include an understanding of people's perceptions of flood risk (Santoro et al., 2019), localised NBS benefits and co-benefits (Giordano et al., 2020; Coletta et al., 2021), as well as NBS governance approaches that recognise the situated knowledge of individuals in local resilience (Grace et al., 2021) and that are purposely designed to ask questions of who, why, how and what (Malekpour et al., 2021).

SM6.3.2.4.6 Livelihoods: positive moderate (medium agreement, robust evidence)

There is *medium agreement* that NBS increases economic activities such as fishing and tourism and creates recreation opportunities (Langergraber et al., 2020). There is strong evidence on resources collected and used in mangrove ecosystems, highlighting the importance of geographical location, gender and age categories that drive variation, especially in the Global South's coastal towns (Gnansounou et al., 2021; Seary et al., 2021; Mallick et al., 2021). Research on the income generated by kelp forest restoration is also increasing (Blamey and Bolton., 2018; Grover et al., 2021) There is strong agreement that the loss of mangroves will have negative effects on food provision (Bernardino et al., 2021).

SM6.3.2.4.7 Health: positive moderate (high agreement, limited evidence)

There is widespread agreement that NBS foster human health and well-being, especially in urban areas (Kabish et al., 2017; Panno et al., 2017), but the results remain broadly inconclusive due to context dependency and socioeconomic confounders. There is some agreement that a greater recognition of the relationship between nature exposure and mental health may also highlight income-related inequalities and provide one of many possible pathways to reduce them (Bratman et al., 2019). However, the evidence for the linkages between NBS, specifically for coastal flood protection, and health of low-income communities remains understudied.

SM6.3.2.4.8 Ecological: positive high (high agreement, medium evidence)

Modelling shows that NBS can enhance multi-functional and multi-scale natural coastal processes providing habitat for wildlife, such as birds (Kim et al., 2018), but evidence is limited. There is strong evidence that NBS promote the transition from open to closed loop cycles by restoring water supplies, such as nutrients that fit into natural water and nutrient cycles (Raymond et al., 2017; Langergraber et al., 2020; Cohen-Shacham et al., 2016; O'Hogain et al., 2018; Ghafourian et al., 2021). Understanding the resilience benefits of oyster reef restoration, for example, is also increasing (Chowdhury et al., 2021; Yurek et al., 2021; Uddin et al., 2021).

SM6.3.2.4.9 Flexibility post-deployment: positive moderate (high agreement, limited evidence)

There is high agreement that as urban centers experience higher amounts of heatwaves, NBS can also offer cooling services, though most evidence largely relates to green infrastructure for stormwater reduction, such as pocket parks and larger urban parks in European cities (Bayulken et al., 2021; Augusto et al., 2020; Sebastiani et al., 2021). However, studies examining cooling benefits of urban vegetation include coastal vegetated areas and demonstrate how coastal ecosystem restoration for storm surge protection can also be utilised for recreation, cooling benefits and more. Still, evidence from green coastal infrastructure is largely understudied, limiting general knowledge about flexibility to adapt to new hazards.

SM6.3.2.4.10 Deployable at scale: positive moderate (medium agreement, limited evidence)

There is *high agreement* of the relevance of large scale NBS for protecting coastal areas including many existing projects investing in large coastal restoration in urban regions (Thorslund et al., 2017). However, there is also *high agreement* on the institutional, legal, political, financial and technical (Arkema et al., 2017; Kabisch et al., 2016; Nesshöver et al., 2017; Fastenrath et al., 2020) challenges for mainstreaming NBS. For instance, the lack of a metropolitan-scale implementation agencies or mechanisms creates challenges to reach new stages of NBS strategies. Scalability challenges, especially in the Global South, are linked to lack of modelling due to substantial data requirements on climatic hazards, bathymetry and elevation, ecosystems, land uses and asset distribution (Guzman et al., 2017). There is some evidence that in small US communities, limited capacity of staff, expertise and funding to comply with federal regulations limits NBS implementation (Tilt and Reis 2021).

SM6.3.2.4.11 Benefit to other infrastructure systems adaptation: positive moderate (high agreement, medium evidence)

There is *high agreement* that NBS can have a positive effect on other infrastructure by limiting storm surge impacts and improving performance of other adaptive measures (Ozment et al., 2019). However, evidence to date is often based on model results, with less empirical case studies to demonstrate impact. One study, for instance, showed how a green infrastructure network can reduce coastal vulnerability by connecting green spaces (Jeong et al., 2021).

SM6.3.2.4.12 Economic feasibility: positive high (high agreement, medium evidence)

There is general agreement, especially in wealthier countries, with comprehensive modelling evidence especially from the USA and the EU, that NBS adaptation could be among the most cost-effective options among a suite of grey to green options (Reguero et al., 2018; Faivre et al., 2017; Costanza et al., 2021). NBS cost-effectiveness varies depending on the geographical location, whether co-benefits are measurable and whether local management practices, such as water quality improvement plans, are in place to protect NBS functionality (Hafezi et al., 2021). Where low operating costs and sustainability are preferred, and the cost of land is not prohibitive, NBS are desirable (White et al., 2021).

SM6.3.2.4.13 Mitigation co-benefit: positive moderate (medium agreement, medium evidence)

There is a growing consensus that NBS can influence urban micro-climate and contribute to circular economy (CE) approaches, through the establishment of ecosystem services that reduce the impacts of urbanisation (Langergraber et al., 2020; Pearlmutter et al., 2019. Some evidence also exists that multiple types of green infrastructure, especially mangroves and their soils (Sutton-Grier et al., 2015; Keith et al., 2021; Jakovac, et al., 2020; Rovai et al., 2018), and the combination of seagrass establishment and human-made structures (Serrano et al., 2020) can aid carbon sequestration.

SM6.3.2.4.14 Targets reducing poverty and marginalisation: positive small (medium agreement, limited evidence)

There is general agreement that NBS, especially mangroves and to a lesser extent, kelp forests (see Livelihoods), contribute to economic livelihoods (zu Ermgassen et al., 2021), though more direct impacts on poverty reduction and marginalisation remains understudied.

SM6.3.2.4.15 Inclusive and locally accountable: positive small (low agreement, limited evidence)

Planning for NBS can be equitable if decision making is done with and for communities who are directly or indirectly impacted by their flood protection and other co-benefits (Derkzen et al., 2017; Heckert et al., 2018; Haase et al., 2017). Evidence for inclusion and local accountability specifically for NBS for flood protection is still, however, limited. The need for clear guidelines establishing the role of government and other actors in participatory mangrove decentralised resource management is highlighted (Arumugam et al., 2021). Understanding user satisfaction and value perceptions for coral reef attributes is also deemed important for restoration initiatives (Fiore et al., 2020; Hein et al., 2019).

SM6.3.2.4.16 Social transformation: positive moderate (medium agreement, limited evidence)

The conditions by which NBS for flood protection may bring societal transformation vary, but there is some agreement around a suite of characteristics. For transformational adaptation to occur, it has to be system-wide (Fedele et al., 2019), restructuring (Pelling et al., 2015), path shifting (Colloff et al., 2017), innovative and multi-scale (Kates et al., 2012). There is *limited evidence* demonstrating how these characteristics actually unfold in time in specific localities. For instance, mangrove-based coastal fisheries are enacting some principles to adapt to climatic hazards in Bangladesh (Islam et al., 2021). There is some evidence that as climate change impacts the functionality of mangroves (Tallie et al., 2020), resource-dependent groups will have to shift their patterns of food production (Bernardina et al., 2021). Overall, impacts on social transformation from NBS for coastal protection projects requires further study.

SM6.3.2.4.17 Ecological transformation: positive small (medium agreement, medium evidence)

Although there is agreement that NBS can lead to lasting ecosystem health, there is also some evidence that changes in the land use, water levels and storm intensities and frequencies can have significant implications on the health and integrity of NBSs and the services they provide (Conger and Chang, 2019). Especially with climate change and the associated increases in global sea levels and acceleration of storm intensities and frequencies, the vulnerability of NBS can potentially reduce, if not eliminate, its coastal protection benefits (Dutra et al., 2021; Taillie et al., 2020; Bolle et al., 2021; Cameron et al., 2021). Yet there is also some evidence that NBS have response mechanisms such as accretion or migrating along the coast to deal with these hazards (Mentaschi et al., 2018; Feagin et al., 2015)

SM6.3.2.5 Riverine Flood Impact Reduction (see Section 6.3.3.5)

SM6.3.2.5.1 Multiple climate hazards: positive high (high agreement, robust evidence)

Well-connected and protected riparian corridors combined with catchment-wide flow attenuation strategies, including city-wide green stormwater infrastructure systems, can mitigate multiple climate-related hazards, including riverine flooding, but also water quality deterioration (Alves et al., 2019), droughts (Kalantari et al., 2018), thermal regulation and urban heat island mitigation (Majidi et al., 2019), and landslide risk (Ruangpan et al., 2020), as well as improve water and food security (Grantham et al., 2019).

SM6.3.2.5.2 Systemic vulnerability reduction: positive small (medium agreement, medium evidence)

Restricting floodplain development and restoring floodplains can help address patterns of residential segregation leading to uneven risk exposure, especially in countries such as the USA where racial and economic discrimination has resulted in patterns of uneven flood vulnerability, although these effects are complicated by luxury development in floodplains and coastlines (Collins et al., 2018). Well-connected greenspaces, which include riparian networks, can also address disparities in recreational opportunities, health and pollutant exposure, though this also depends upon reductions in the sources of contaminants and the social determinants of health (Twohig-Bennett and Jones, 2018). Additionally, flood-oriented NBS, if not planned and implemented with sensitivity to social conditions and needs, can exacerbate systemic vulnerability by displacing more economically vulnerable residents to other more flood-prone areas, though if implemented with sensitivity, they can support community development (Shi, 2020.

SM6.3.2.5.3 Reduces new hazard exposure generated: positive small (medium agreement, medium evidence)

City- and basin-wide NBS for riverine flood impact reduction can reduce the generation of new hazards by 'making space for water' which eliminates a false sense of security provided by traditional flood management approaches (Turkelboom et al., 2021; Ruangpan et al., 2020). Additionally, successful flood mitigation through NBS requires implementation at sufficient scales (Vojinovic et al., 2021; Raška et al., 2019). Still, with shifting baselines of flood events, NBS can also lead to similar paradoxes of flood protection, where a false sense of security is provided by NBS if city-wide systems of flood mitigation are overwhelmed by events of unforeseen magnitudes (Ruangpan et al., 2020).

SM6.3.2.5.4 Transfer of risk: negative moderate (high agreement, medium evidence)

Overall, NBS approaches for flood reduction provide higher on-site flood mitigation and reduced risk transfer to downstream areas compared with traditional grey infrastructure approaches of channelisation and damming (Ruangpan et al., 2020). There are limited studies of mitigation of urban flooding with NBS through urban green infrastructure that show that there can be risk transfer to nearby residents via increased basement flooding from infiltration measures, or where there is limited capacity for storage in shallow groundwater environments (Zhang and Chui, 2019). Additionally, if not managed adequately, NBS can exacerbate mosquito-borne illnesses through creation of standing water, though these risks can be managed through improved design (Wong and Jim, 2018; Lõhmus and Balbus, 2015).

SM6.3.2.5.5 Social capital: positive moderate (high agreement, medium evidence)

Well-designed NBS for riverine flood reduction, which require extensive green space networks, provide multiple social benefits including improved gathering places, recreation opportunities and aesthetics, as well as a sense of place and identity, all of which can help build social capital (Venkataramanan et al., 2019).

SM6.3.2.5.6 Livelihoods: positive moderate (low agreement, medium evidence)

If deployed at scale using appropriate governance systems, flood mitigation NBS can support community development through fisheries and sustainable agriculture (Shi, 2020), with some notable river restoration projects finding significant economic benefits of restored river systems (e.g., Bellas and Kosnik, 2019). However, there is disagreement about other potential benefits, such as positive impacts to tourism and recreation industries (Deffner and Haase, 2018; Johnson et al., 2018).

SM6.3.2.5.7 Health: positive high (high agreement, medium evidence)

NBS for flood mitigation have many direct and indirect benefits for public health, including reduced impacts of floods on acute mortality, prevalence of waterborne pathogens, and indirect impacts such as increasing recreation opportunities with benefits to physical and psychological health (Van den Bosch and Sang, 2017).

SM6.3.2.5.8 Ecological: positive high (high agreement, robust evidence)

Well-connected riparian networks and distributed flood mitigation NBS form the backbone of urban and regional ecological systems, and in turn can have large positive impacts on habitat abundance, connectivity and quality (Fuller et al., 2015), water quality and the restoration of chemical, nutrient, sediment and energy flows in ecosystems (Ferreira et al., 2021; Turkelboom et al., 2021; Dalwani and Gopal, 2020; Ronchi and Arcidiacono, 2019; Krauze and Wagner, 2019; Keestra et al., 2018).

SM6.3.2.5.9 Flexibility post-deployment: positive small (medium agreement, limited evidence)

NBS for riverine flood impact reduction has not been well studied for flexible adaptation post-deployment, though green infrastructure interventions are shown to provide multiple benefits (Keeler et al., 2019). However, floodplains are dynamic environments evolving in relation to watershed, hydro-meteorological and ecological processes. In a changing climate, managing upslope NBS and engaging non-human biological agents (e.g., beavers, riparian vegetation) that affect runoff responses is a critical component of adapting NBS for maintaining and enhancing effectiveness (Johnson et al., 2020).

SM6.3.2.5.10 Deployable at scale: positive moderate (medium agreement, medium evidence)

NBS for riverine flood mitigation is already being implemented at large spatial scales. Research is clear that effective flood impact reduction NBS requires basin-wide implementation, as well as integration into complex, and often fractal, catchment geometries at the city scale. There is widespread agreement that such systematic reconfigurations of hydrological infrastructures are required to address the need for climate resilience (Sofi et al., 2020; Boltz et al., 2019), especially within cities. However, sub-basin delineation within cities remains an analytical challenge, especially given incomplete or non-existing data on human constructed drainage networks (Brasil et al., 2021; Kumar et al., 2021; Ferreira et al., 2020; Randall et al., 2019). Effective deployment thus requires integrating flood mitigation NBS into existing drainage networks and catchment geometries, with consideration for permeabilities and interactions with other built infrastructures, and the perceived and objective effectiveness of flood mitigation NBS critically depends upon the scale of their implementation (Pagano et al., 2019; Raška et al., 2019).

SM6.3.2.5.11 Benefit to other infrastructure systems adaptation: positive moderate (medium agreement, medium evidence)

Preventing and mitigating riverine floods can have positive impacts on other infrastructure systems (Alves et al., 2020) as NBS are increasingly implemented through integration into existing grey infrastructure systems (Ncube and Arthur, 2021; Mulligan et al., 2020), with the goal of increasing disaster risk reduction (Denjean et al., 2017) through reducing downstream flood impacts on both infrastructure and people. These hybrid approaches appear to offer numerous benefits to grey flood infrastructure adaptive capacity and can increase the resilience of other infrastructures systems affected by flooding (Neuman et al., 2015). Recent studies examine the trade-offs of urban NBS through the water–food–energy nexus, identifying a need to examine trade-offs of specific NBS in context (Shah et al., 2021).

SM6.3.2.5.12 Economic feasibility: positive moderate (low agreement, medium evidence)

Increasing climatic extremes have increased the cost of flood damages, along with the costs of maintaining flood infrastructure systems (Bevacqua et al., 2019; Dottori et al., 2018; Jongman, 2018). NBS, including making space for flood waters, are an increasingly economic option for responding to increasing flood risks, and yet a primary challenge is in addressing the opportunity cost of foregoing development within floodplains (Pour et al., 2020; Alfieri et al., 2016). Thus, while the infrastructure system costs of NBS are much lower compared with grey infrastructure responses (Moudrak et al., 2018; Ward et al., 2017), the space required comes with considerable perceived costs. Since these costs can be a matter of perception, and economic benefits of floodplain development come with significant risk exposure, it is *likely* that the perception of land values will continue to shift to favour making space for flood waters as insurance rates continue to evolve to reflect shifting risk exposure (Denjean et al., 2017).

SM6.3.2.5.13 Mitigation co-benefit: positive moderate (high agreement, robust evidence)

NBS for flood mitigation provide a net sequestration of atmospheric CO_2 (Seddon et al., 2021), largely through eventual export of organic matter to deep ocean storage (Scheingross et al., 2021). NBS for riverine flood mitigation also provide a net GHG emission reduction benefit as compared with grey infrastructure approaches that retain significant amounts of standing water, due to the large methane emissions of reservoirs and larger stormwater retention facilities (Deemer and Holgerson, 2021; Maavara et al., 2020; Félix-Faure et al., 2019; Phyoe and Wang, 2019).

SM6.3.2.5.14 Targets reducing poverty and marginalisation: positive small (low agreement, medium evidence)

Flood reduction through NBS can reduce poverty and marginalisation issues caused by acute and chronic flooding in a variety of contexts (Ambrosino et al., 2020; Urama et al., 2019). If done at scale, NBS can also increase economic security of marginalised populations (Shi, 2020) who have also been historically disproportionately impacted by grey flood control infrastructures (Hay et al., 2019; Liao et al., 2019; Del Bene et al., 2018; Anguelovski et al., 2016; Aiken and Leigh, 2015). However, there is limited existing evidence that NBS are being widely deployed in such a way that addresses these historical patterns and practices (Anguelovski et al., 2016).

SM6.3.2.5.15 Inclusive and locally accountable: positive small (medium agreement, limited evidence)

Flood mitigation NBS can be implemented through local governance, including their integration of NBS into grey infrastructure systems (Mulligan et al., 2020), though evidence is limited from local case studies. However, implementing NBS at the scale required often requires centralised planning and coordination at city and regional scales for larger river systems (Vojinovic et al., 2021; Zingraff-Hamed et al., 2020). Local flooding issues can be addressed at hyper-local scales, down to the individual land owner (Gutman, 2019). There is an emerging consensus that successful flood mitigation NBS needs multi-level and collaborative governance structures (Martin et al., 2021; Albert et al., 2019).

SM6.3.2.5.16 Social transformation: positive small (low agreement, limited evidence)

Scholars have noted fundamental social transformations occurring from governance regimes associated with NBS for some time now (e.g., Schoeman, 2006; Steffen et al., 2018). Though there is *limited evidence* of where implementation of NBS for riverine flood protection has stimulated social transformation, there is increasing evidence suggesting that successful flood mitigation NBS may require fundamental and systemic change in patterns of land use, along with a systemic shift in the governance of human–nature relations (Welden et al., 2021). If NBS is deployed collaboratively and transparently, then positive social transformation is possible (Martin et al., 2021; Albert et al., 2019; Wong et al., 2020). However, critical scholars of infrastructure have observed how the turn towards nature as infrastructure may simply broaden and deepen (Scott, 2008) historically oppressive and extractive governance structures in the name of ecological security (Carse, 2012; Pritchard, 2011; Molle, 2009). A need remains to examine the roles of labour, delineations of territory and the financing of NBS (Nelson and Bigger, 2021) to understand positive or negative societal transformations driven by the multi-scalar implementation of flood-focused NBS.

SM6.3.2.5.17 Ecological transformation: positive high (medium agreement, medium evidence)

NBS for riverine flood mitigation can lead to significant positive changes in riverine and terrestrial ecosystems if applied at appropriate scales (Hobbie and Grimm, 2020; Raška et al., 2019; Rowiński et al., 2018). These changes include improving habitat quality and connectivity, and concomitant reversals of long-term biodiversity decline (Reid et al., 2019). In comparison with grey infrastructure approaches for flood mitigation in cities of channelised streams, piped conveyance and limited flow attenuation structures, NBS can have large positive impacts on ecosystem structure and function, even in degraded urban rivers (Groffman et al., 2003; Boltz et al., 2019; Palmer and Ruhi, 2019). NBS for flood mitigation, including restored floodplains, streams, rivers, wetlands, and diverse sets of flow attenuation facilities including green roofs, walls, bioswales and tree trenches can be particularly useful for restoring society–nature relationships in rapidly urbanising areas (Hérivaux and Le Coent, 2021; Lafortezza and Sanesi,2019; Dhyani et al., 2018).

SM6.3.2.6 Water Provisioning and Management (see Section 6.3.3.6)

SM6.3.2.6.1 Multiple climate hazards: positive high (high agreement, robust evidence)

NBS can increase water infiltration and reduce surface runoff, thus enhancing groundwater recharge and the slow movement of water through the subsurface to rivers, lakes and streams. In undeveloped areas upstream of a city, natural vegetation helps infiltrate rainwater, and store water between rainfall events. NBS such as street trees, parks and open spaces, community gardens, and engineered systems such as rain gardens, bioswales or retention ponds that protect or restore the natural infiltration capacity of a watershed can also increase water supply (Keeler et al., 2019; Brauman et al., 2019. These NBS are often designed to increase stormwater infiltration but can be larger in scope and scale such as where land management is implemented at the watershed scale to provide water supply for drinking water, agricultural use and other urban and regional water needs (Abell and Johnson, 2017). NBS for water management can also be an effective approach to reduce water-related climate risks and strengthen water security, particularly in developing countries (Drosou et al., 2019; Krauze and Wagner, 2019). Hybrid green infrastructure has been shown to effectively complement traditional grey infrastructure in cities as an effective NBS to manage climate hazards related to stormwater management, coastal and inland flooding, and compromised drinking water systems, thus increasing water security (Boholm and Prtuzer, 2017). However, while NBS can provide several forms of hazard reduction such as reducing the volume of floodwater, stabilising riverbanks and reducing erosion, there is still *limited evidence* to suggest NBS for water management can sufficiently address non-water related climate hazards (Kabish et al. 2016, Schanze 2017).

SM6.3.2.6.2 Systemic vulnerability reduction: positive moderate (medium agreement, limited evidence)

Nature-based approaches to water management, drinking water provisioning and agriculture can reduce the vulnerability of social–ecological systems by increasing water efficiency, combating erosion and local water pollution, and reducing water footprints and food waste (Boelee et al., 2017). Integrated urban watershed management has been shown to increase socioeconomic outcomes in some communities by increasing opportunities for employment in agriculture, horticulture, afforestation and other enterprises (Tesfaye, Debebe and Yakob, 2018). Some research highlights how NBS that protect or restore the natural infiltration capacity of a watershed can increase the water supply service in some areas, improve drought protection, assist in food security and economic provisioning, and provide resilient water supply (Oral et al., 2020) in ways that may impact social vulnerability. Moreover, increasing the amount of green space in urban areas can secure and regulate water supplies, improving water security (Liu and Jensen, 2018). However, evidence will likely remain limited that documents how NBS for water provisioning may reduce systemic vulnerability or increase water security in the long term without significant investment and coordination between diverse stakeholders (Kabisch et al., 2016).

SM6.3.2.6.3 Reduces new hazard exposure generated: positive moderate (medium agreement, limited evidence)

NBS for water management or provisioning can also reduce exposure to climate impacts and hydrological risks ranging from flooding to urban heat, erosion, and water scarcity (Chausson et al., 2020; Valenzuela et al., 2020). The protection of coastal areas, as well as restoration of wetlands for instance, can improve water security and protect against flooding and storm surges and can also promote fire risk reduction (Hobbie and Grimm, 2020). However, there is still *limited evidence* to assess the full potential of NBS for water provisioning for reducing the exposure to new hazards generated by a changing climate (Shar et al., 2020) or by shifting human behaviour in ways that reduce exposure.

SM6.3.2.6.4 Transfer of risk: unknown (medium agreement, limited evidence)

There is limited study of the potential transfer of risk or impacts from NBS for water provisioning and management to people infrastructure (Alves et al., 2019; de Macedo et al., 2021). The use of green infrastructure for stormwater management has been shown to reduce runoff during heavy precipitation events, and thus reduce the risk of combined sewer overflows, while also enhancing water quality in urban areas providing risk reduction (Liu et al., 2020; Debele et al., 2019; Sahani et al., 2019). In a study of urbanised areas in the African region, researchers note evidence that NBS such as natural water management and preservation of wetlands and forested areas is effective in flood risk reduction, can prevent loss of water resources and improve water cycling and provisioning through processes such as infiltration, retention and interception (Acreman et al., 2021). The transfer of risk to human communities or infrastructure is mostly unknown given *limited evidence*.

SM6.3.2.6.5 Social capital: positive moderate (medium agreement, limited evidence)

NBS for water management or provisioning may enhance levels of social capital through forms of economic empowerment and by increasing a community's participation in resource co-management and governance (Welden, Chausson and Melanidis, 2021; Syafri et al., 2020; Obando et al., 2018). A study of a participatory integrated watershed management programme in Ethiopia for instance, demonstrated an increase in employment opportunities and income sources, as well as other forms of social capital by directly involving community members in decision making about appropriate nature-based technologies, training and economic pathways (Tesfaye, Debebe and Yakob, 2018). There is still *limited evidence* globally on the connections between NBS for water management and potential positive impacts on social capital (Auer et al., 2020; Valenzuela et al., 2020).

SM6.3.2.6.6 Livelihoods: positive moderate (medium agreement, medium evidence)

NBS such as integrated urban water management that centres on community involvement may improve livelihoods through the creation of jobs, infrastructure cost-savings, health and other economic outcomes (Rohini et al., 2017; Wani et al., 2008; Larson, Wiek, Withycombe Keeler, 2013; Nerkar et al., 2016). In some cases, the use of NBS has been shown to provide economic savings by minimising the impacts of sea level rise, inland and pluvial flooding, stormwater from extreme precipitation and maintenance costs of preserving clean water sources (Jongman, 2018). A large majority of research however focuses solely on assessing the stormwater-related economic benefits of NBS, and often does not provide a comprehensive economic or financial valuation for cities to readily leverage (Hamann et al., 2020; Ashley et al., 2018).

SM6.3.2.6.7 Health: positive high (high agreement, medium evidence)

NBS for water management has been shown to provide benefits to human health including physical well-being and mental health (Keeler et al., 2019). Some forms of NBS may provide opportunities for recreation and physical activity and can also provide cleaner water and opportunities to effectively manage stormwater to reduce the health impacts of combined sewer overflow events (Venkataramanan et al., 2019; Braubach et al., 2017). A study of urbanising East African communities suggests that NBS focused on improving water security, retention and purification have co-benefits such as increased access to physical activity and recreation, as well as biodiversity conservation (Kalantari et al., 2018). However, research to date has focused more heavily on the co-benefits of green spaces and infrastructure, providing *limited evidence* for the role nature-based water management strategies can play in improving direct health outcomes and, in particular, for low-income or at-risk communities (Marques et al., 2020; Kondo et al., 2015).

SM6.3.2.6.8 Ecological: positive high (high agreement, robust evidence)

Urban NBS, such as through investments in green infrastructure, can regulate critical ecosystem services through flood protection and water flow maintenance, improving water quality, micro and regional climate regulation, and overall global climate regulating through carbon storage and sequestration (Babí Almenar et al., 2021; Baró and Gómez-Baggethun, 2017). Particular forms of NBS such as infiltration basins, constructed wetlands or rain gardens have been shown to be effective in urban water pollution control, removing organic and inorganic pollutants, pesticides, pharmaceuticals and heavy metals with positive impacts on ecosystems (Seddon et al., 2020). NBS also provides key provisioning services such as providing drinking water and securing freshwater supplies, as well as playing a key role in supporting food and cultural services (Brill, Anderson, O'Farrell, 2017).

SM6.3.2.6.9 Flexibility post-deployment: positive moderate (medium agreement, medium evidence)

NBS for water management or provisioning, such as the deployment of green infrastructure including bioswales, retention ponds, stormwater catchment systems or constructed wetlands can be flexible post-deployment for providing risk reduction to other climate hazards (Qi et al., 2020). While NBS have the potential to provide several co-benefits to both human communities and the environment, research shows that these solutions also require ongoing maintenance, as well as integrated planning and coordination across sectors long term, which can be prohibitive to ensuring their success and flexibility (Nelson et al., 2020; Fastenrath, Bush and Coenen, 2020). Evidence remains limited to conclude that NBS for water management and provisioning are adequately flexible, post-deployment (Fastenrath et al., 2020).

SM6.3.2.6.10 Deployable at scale: positive moderate (high agreement, medium evidence)

Urban NBS for water management and provisioning are already being deployed at large spatial scales, with impacts that address the risks and hazards of climate change, while addressing water security in urban areas (Bichai and Flamini, 2018). However, research shows that restoration efforts or the installment of new urban green infrastructure can be challenging to scale, as large areas are often required for implementation and may take a long time for systems to demonstrate significant benefits, as detailed in an analysis of the Living Melbourne strategy in Australia (Fastenrath et al., , 2020). Additionally, in urban areas, significant alterations to water bodies, coastlines, or rivers are difficult to reverse, revealing the complexity of such cross-scale challenges (Boelee et al., 2017).

SM6.3.2.6.11 Benefit to other infrastructure systems adaptation: positive small (medium agreement, medium evidence)

The effectiveness of NBS co-benefits is largely dependent upon local contexts, soil types and conditions, flood parameters, and NBS design, among other factors (Hobbie and Grimm, 2020). Co-benefits of NBS for water provisioning has potential to increase resilience of interconnected infrastructure systems such as transportation and food and energy systems, though impacts are mostly through NBS for riverine and coastal flood protection rather than for water provisioning that has better documented impacts preventing damage to public infrastructure and private properties (Depietri and McPhearson, 2017; Stefanakis et al., 2021). In urban areas located along coastlines or embedded within riverine environments, the use of NBS may aid cities in achieving broader adaptation goals, as well as provide co-benefits such as increasing biodiversity and ecological adaptation to climate change (Hobbie and Grimm, 2020; Keesstra et al., 2018).

SM6.3.2.6.12 Economic feasibility: positive high (high agreement, robust evidence)

Nature-based approaches to watershed management and drinking water provisioning can be more cost-effective and economically feasible compared with traditional grey infrastructure or engineered systems (Boutwell and Westra, 2016; Kroeger et al., 2019). For example, the Staten Island Bluebelt in New York City, a system of constructed wetlands for ecosystem-based stormwater management, is estimated to generate capital cost savings of approximately USD 30 million (McPhearson et al., 2018). NBS interventions can also provide energy savings by cooling urban environments through shading, evaporative cooling and wind shielding, reducing the urban heat island, while also providing a cost-effective climate solution to greenhouse gas emissions reduction (Stefanakis et al., 2021). Additionally, the use of naturally sourced and locally available surface or groundwater, and rainwater harvesting, is often more economically and energy efficient, particularly for drought-prone urban areas (Pearlmutter et al., 2019; Hale et al., 2021; Song et al., 2019).

SM6.3.2.6.13 Mitigation co-benefit: positive moderate (high agreement, medium evidence)

NBS such as vegetated coastal wetlands, conserved watersheds, or peatland conservation can serve as a net sink of greenhouse gas emissions (GHG); peatlands in particular are recognised as a critical carbon sink, as well as intact vegetated coastal wetlands (Tanneberger et al., 2021; Negandhi et al., 2019) and yet carbon storage associated more specifically with water provisioning is understudied, despite potential to also provide mitigation co-benefits. The conversion of wetlands or peatlands to other land uses, such as agriculture, grasslands, developed areas or for gas extraction, may reduce the ability of systems to absorb greenhouse gas emissions and encourage erosion (Crooks et al., 2018). Green and blue infrastructure interventions are thus recognised as an effective form of carbon sequestration (Alves et al., 2019; Fenner, 2017).

SM6.3.2.6.14 Targets reducing poverty and marginalisation: positive moderate (low agreement, limited evidence)

Issues of water security and urban flooding have been shown to disproportionately impact vulnerable groups, with an estimated 59% of urban populations in developing countries without access to piped water (Keeler et al., 2019). NBS for water management or provisioning have potential to consider the associated equity dimensions that could have a synergistic effect on reducing poverty or marginalisation or provide benefits to vulnerable communities (Hoover et al., 2021; Collins et al., 2018; Shi, 2020). Similarly, NBS for water management deployed at various scales face procedural, distributive and other logistical challenges for how to effectively include diverse stakeholders in evidence-based decision making and climate governance (DuPuis and Greenberg, 2019). While there is great potential for NBS to improve equity measures and benchmarks for cities, there is still *limited evidence* to suggest that NBS are a reliable means to reduce poverty and marginalisation of vulnerable groups (Seddon et al., 2020).

SM6.3.2.6.15 Inclusive and locally accountable: positive small (medium agreement, limited evidence)

NBS for water management have potential to be inclusive, 'bottom-up' and community-based by engaging a diversity of stakeholders and addressing local contexts to ensure successful implementation (Drosou et al., 2019). However, case studies documenting successful inclusive processes are limited. While cities may seek to achieve these objectives, there is still *limited evidence* to suggest that NBS are inherently inclusive or locally accountable and may result in trade-offs such as displacement (Scheidel and Work, 2018). Researchers stress how cities have historically failed to involve local communities and Indigenous groups, which ignores critical cultural links and identities that are important to successful NBS adoption and implementation (Drosou et al., 2019). In a study of green–blue infrastructure adoption in Semarang, Indonesia, researchers found that a lack of public awareness, funding and high costs of implementation, as well as fragmented policy and regulatory frameworks directly influenced the effectiveness of involving local residents in flood or urban water management actions (Srivastava and Mehta, 2018).

SM6.3.2.6.16 Social transformation: positive small (high agreement, limited evidence)

NBS for water management and provisioning can promote forms of social transformation by securing water security and enabling a shift from unsustainable development to address multiple environmental and social challenges (Steffen et al., 2018; Sartison and Artmann, 2020). Practitioners and researchers increasingly advocate not only for approaches to NBS such as the water-sensitive city model or integrated urban water management (IUWN), but also biocultural approaches which hold transformative potential, connecting cultural, social and economic issues to human well-being and social justice (Welden et al., 2021). While there is great potential for social transformation through NBS for water management, there is still *limited evidence* that such transformations are occurring through current NBS projects (Wong et al., 2020).

SM6.3.2.6.17 Ecological transformation: positive moderate (high agreement, medium evidence)

NBS for water management and provisioning provide several co-benefits to local and regional ecosystems, providing habitat reserves and corridors for species migration, increasing biodiversity levels and connecting diverse flows in the urban water cycle to promote ecological transformation (Hobbie and Grimm, 2020; Rowiński et al., 2018). Researchers point to the shortcomings of traditional grey infrastructure, which many cities still rely upon for drinking water distribution, stormwater collection and wastewater treatment, highlighting the advantages of urban ecological infrastructure that takes advantage of ecological processes and provide alternative water supplies (Kozak et al., 2020). Evidence suggests that NBS through constructed wetlands, green walls, roof gardens and vegetated drainage basins can be used to support stormwater and wastewater treatment while also offering ecological co-benefits (Filoso et al., 2017). These solutions are particularly critical for cities in the Global South where a large majority of residents rely on urban nature for their water supply, often outside the traditional grey infrastructure, raising important environmental justice concerns (Keeler et al., 2019).

SM6.3.2.7 Food Production and Security (see Section 6.3.3.7)

SM6.3.2.7.1 Multiple climate hazards: positive moderate (high agreement, medium evidence)

Urban agriculture (UA), such as community gardens, rooftop gardens, vertical indoor gardens and urban agroforestry, can provide stormwater attenuation and reduce urban heat island (UHI) effects (Goldstein et al., 2016). However, the potential effect of UA will vary depending on factors including the size of the allotment, available land, soil quality, climate, and water and light availability, which may be reduced from building shading (Keeler et al., 2019; Clinton et al., 2018; van Vliet, Eitelberg and Verburg, 2017).

SM6.3.2.7.2 Systemic vulnerability reduction: positive moderate (high agreement, medium evidence)

UA can reduce physical vulnerability by mitigating stormwater flooding and UHI, and by providing nutrient cycling (Goldstein et al., 2016). UA can also help to address food insecurity through the localised production of food (Orsini et al., 2013), production levels are dependent on factors such as level of farming skill and supporting infrastructure such as running water, cultivation technique and crop species selection (Barthel, Parker and Ernstson, 2015). UA, and in particular community and allotment gardens, have also been found to alleviate social vulnerability by contributing to a sense of cultural belonging, a sense of place and community cohesion (Andersson, Barthel and Ahrné, 2007; Veen et al., 2016). However, physical access to UA, available time, cultural values around food production and level of familiarity with other garden users may moderate this outcome (Keeler et al., 2019).

SM6.3.2.7.3 Reduces new hazard exposure generated: positive negligible (medium agreement, limited evidence)

Extreme heat, drought and other climate hazards can negatively impact crop production and flooding, or other extreme weather events can disrupt food supply chains (Schipanski et al., 2016). UA can support improved food security by providing individuals with knowledge about UA and the physical resources to engage with localised farming practices as opposed to relying on conventional global food systems in ways that may reduce exposure to some hazards (Schipanski et al., 2016; Barthel et al., 2010; Frayne, McCordic and Shilomboleni, 2014; Grewal and Grewal, 2012). However, there is *limited evidence* and potential benefits are dependent on factors including the amount of available land and the suitability of the climate to growing crops year-round (Badami and Ramankutty, 2015). For example, regions with warmer year-round climates can support multiple cycles of crop growing (Zezza and Tasciotti, 2010).

SM6.3.2.7.4 Transfer of risk: unknown (low agreement, limited evidence)

UA requires water, energy, land and labour, creating demand on existing infrastructure and potentially diverting resources that could be directed elsewhere (Mohareb et al., 2017). Less sustainable waste management practices and the use of pesticides that increase polluted runoff are additional areas where risk may be transferred to other people (Mohareb et al., 2017), but there is *limited evidence* of increased risks to climate hazards in other areas directly attributed to UA practices.

SM6.3.2.7.5 Social capital: positive moderate (medium agreement, medium evidence)

UA, and in particular allotment and community gardens, has been found to build social capital by enabling cross-cultural interactions, fostering cultural heritage and sense of place, and enhancing social cohesion (Cameron, 2012 Horst, McClintock and Hoey, 2017, Camps-Calvet et al., 2016). These benefits can vary based on the level of comfort and familiarity that gardeners have with the neighbourhood of the garden and their perception of the garden as a welcoming space (Armstrong, 2000). Equity concerns, however, related to land access and availability have also been cited as potentially impacting social capital outcomes of UA, as well as potentially contributing to gentrification (McClintock, 2018).

SM6.3.2.7.6 Livelihoods: positive small (medium agreement, medium evidence)

In addition to subsistence production, UA may be used to generate income (Keeler et al., 2019). Mobile food markets can be a source of economic activity, especially in urban food deserts where fresh produce is not readily accessible. A documented challenge associated with mobile food markets is the high cost of operations compared with generated revenue (Siegner et al., 2018). However, research in more Global South cases is needed.

SM6.3.2.7.7 Health: positive small (medium agreement, medium evidence)

Health benefits associated with UA include increased levels of dietary diversity and nutrition (Zezza and Tasciotti, 2010). Certain contexts may amplify these benefits, including lower-income areas of cities in higher-income countries and lower-income countries where people are already reliant on agriculture for subsistence and for revenue generation (Armstrong, 2000). UA has been linked to positive mental health outcomes (Soga et al., 2017). However, there are cases in which UA may perpetuate existing environmental health injustices. For example, a case study of UA in Oakland, CA, USA, found that lower-income areas are correlated with higher concentrations of soil contamination, impacting food quality (McClintock, 2012).

SM6.3.2.7.8 Ecological: positive moderate (high agreement, medium evidence)

UA can provide opportunities that expand urban green space and has been linked to a variety of ecosystem services, including pollination, nitrogen fixation, pest control, climate regulation, avoided stormwater runoff, soil formation and maintenance of soil fertility, and, for rooftop gardens, energy conservation via improved insulation (Clinton et al., 2018; Camps-Calvet et al., 2016). These benefits have been found to be more prominent when the previous land use has less ecological value (Nogeire-McRae et al., 2018).

SM6.3.2.7.9 Flexibility post-deployment: positive moderate (medium agreement, medium evidence)

Through the selection of certain crop types, such as larger tree species, UA can be adapted to provide heat reduction and stormwater drainage (Goldstein et al., 2016). Flexibility to provide multi-hazard risk reduction is driven by the multi-functionality of UA and the many ecosystem services that UA can provide. However, any UHI or flood mitigation effects are *likely* to be small in magnitude and dependent on a variety of factors such as total land area, tree species, local climate and soil condition (Clark and Nicholas, 2013).

SM6.3.2.7.10 Deployable at scale: positive small (high agreement, medium evidence)

UA projects are relatively easy to replicate as they can be adapted to the specific regional context by changing attributes such as crop type and UA project type. However, UA food production remains a small percentage of total urban food demand (McClintock, 2014; Clinton et al., 2018; Hara et al., 2018). A study that modelled the output potential for UA found that when factoring in land constraints, total crop production could be reduced to 1–5% of total yield potential (Clinton et al., 2018). Some documented challenges include identifying available space and locating land with uncontaminated soil (McClintock, 2014; Clinton et al., 2018).

SM6.3.2.7.11 Benefit to other infrastructure systems adaptation: positive small (medium agreement, medium evidence)

UA can provide direct benefits to infrastructure adaptation, especially for rooftop gardens which can insulate buildings from heat, increase roof longevity and provide cooling, as well as decrease total energy demand for cooling (Cameron et al., 2012, Qiu et al., 2013, Keeler et al., 2019). However, this potential effect can be small depending on the rooftop garden size relative to the overall building cooling demand (Keeler et al., 2019) and does not provide similar benefits when implemented in ground level areas.

SM6.3.2.7.12 Economic feasibility: positive moderate (high agreement, medium evidence)

UA can be initiated at very small garden scales, and so has high potential economic feasibility but is also variable. The economic feasibility of UA is dependent on factors such as the size of the plot, type of UA project, cost of labour, water and light requirements of the selected crop species under varied regional climates, and crop yield (Keeler et al., 2019; Clinton et al., 2018). Studies show that UA is a current source of food for communities in lower-income areas and has a long-standing history in countries in the Global South (Orsini et al., 2013).

SM6.3.2.7.13 Mitigation co-benefit: positive small (medium agreement, medium evidence)

Outdoor UA can provide a cooling effect and serve as a carbon sink (Goldstein et al., 2016) and rooftop UA can serve as building insulation that reduces energy demand for cooling (Cameron et al., 2012). However, heating requirements for indoor UA can contribute to greenhouse gas emissions when implemented in colder climates, making mitigation benefits highly dependent on the type of UA (Cameron et al., 2012, Mohareb et al., 2017

SM6.3.2.7.14 Targets reducing poverty and marginalisation: positive small (medium agreement, medium evidence)

UA is an existing mode of food supply for communities in lower-income areas globally (Orsini et al., 2013; Saldivar-Tanaka and Krasny, 2004). Researchers have found that UA can contribute to food security and may serve as an important source of food supply in areas considered food deserts, making them an important source of poverty alleviation through increased food security and nutritional diversity (Frayne et al., 2014).

SM6.3.2.7.15 Inclusive and locally accountable: positive small (medium agreement, limited evidence)

There is widespread consensus that UA can enable social cohesion and community development (Keeler et al., 2019; Jacob and Rocha, 2021). UA has also been found to contribute to cross-cultural interactions (Jacob and Rocha, 2021, Shinew et al., 2004). However, cases have also been documented in which there is inequitable access to UA, such as community gardens, especially related to spatial proximity and available time (Keeler et al., 2019, Colding and Barthel, 2013; McClintock, 2018; Bellemare and Dusoruth, 2021). More research is needed to assess equitable access to UA across different contexts (Keeler et al., 2019).

SM6.3.2.7.16 Social transformation: positive moderate (high agreement, medium evidence)

UA is multi-functional and has the potential to provide a host of ecological and social benefits (Keeler et al., 2019). In a departure from neoliberal 'food security' narratives, UA has also been considered as a conduit for food sovereignty and food system transformation (Alkon and Mares, 2012; Siebert, 2020; Tornaghi and Dehaene, 2020), which seeks to democratise food systems and asserts the right of people to produce and define their own food and agriculture systems (Desmarais, 2007). However, inclusive and equitable access to healthy garden plots is critical to ensuring positive social transformation (McClintock, 2018).

SM6.3.2.7.17 Ecological transformation: positive moderate (medium agreement, medium evidence)

UA can foster biodiversity and support pollinators and multiple forms of ecosystem functioning (Goldstein et al., 2016). These benefits are limited by the rate of urbanisation which can reduce land availability and contribute to contaminated soil and poor growing conditions (Follmann et al., 2021). UA characteristics that contribute to UA biodiversity include varied vegetative structure, increased native plant diversity and reduction of urban impervious surface (Lin et al., 2015). A review of literature on the biodiversity benefits of UA found mixed evidence of potential benefits, with the majority of existing studies conducted in North America (Clucas et al., 2018).

SM6.3.3 Grey/Physical Infrastructure

SM6.3.3.1 Built Form (see Section 6.3.4.1)

SM6.3.3.1.1 Multiple climate hazards: positive high (high agreement, robust evidence)

Adaptation of built form can help manage multiple climate risks, especially flood and heat risk (Zhou et al., 2017; Chan et al., 2018; Caparros-Midwood et al., 2019).

SM6.3.3.1.2 Reduces systemic vulnerability: positive high (high agreement, robust evidence)

Adaptation of built form is a systemic vulnerability reduction (Dhar and Khirfan, 2017; Ürge-Vorsatz et al., 2018).

SM6.3.3.1.3 Reduces new hazard exposure generated: positive high (high agreement, robust evidence)

Adaptation of built form can reduce exposure against multiple risks (Schwarz and Manceur, 2015; Caparros-Midwood et al., 2019; Sharifi, 2019).

SM6.3.3.1.4 Transfer of risk: negative small (medium agreement, limited evidence)

Some actions in the built environment could transfer risks elsewhere, for example downstream flood risk (Nicholls et al., 2020; Hewett et al., 2020).

SM6.3.3.1.5 Social capital: positive negligible (low agreement, limited evidence)

Transformation of built form has potential to enhance social capital (Cabrera and Najarian, 2015; Romero-Lankao et al., 2018). Evidence is limited but positive relationships typically exist between design and diversity, but population density is typically negative and less clear (Mazumdar et al., 2018).

SM6.3.3.1.6 Livelihoods: positive moderate (medium agreement, medium evidence)

Increasing density can increase job density and accessibility (Lohrey and Creutzig, 2016; Wiedenhofer et al., 2018; Caparros-Midwood et al., 2019).

SM6.3.3.1.7 Health: positive high (high agreement, robust evidence)

Adaptation of the built environment form can improve air quality, mental health and well-being (Hankey and Marshall, 2017; Yuan et al., 2018; Mouratidis, 2018; Kent and Thompson, 2014).

SM6.3.3.1.8 Ecological: positive moderate (medium agreement, medium evidence)

Adaptation of built form can provide beneficial green space, ecological corridors and other services (Marcus et al., 2020; Childers et al., 2015; Grafius et al., 2018).

SM6.3.3.1.9 Flexibility post-deployment: negative high (high agreement, robust evidence)

Built form locks in for a long time, typically these lock ins have had negative impacts but there is also the opportunity to lock in positive benefits (Ürge-Vorsatz et al., 2018).

SM6.3.3.1.10 Deployable at scale: positive high (high agreement, robust evidence)

Built form adaptation is a broad scale intervention (Dhar and Khirfan, 2017).

SM6.3.3.1.11 Benefit to other infrastructure systems adaptation positive high (low agreement, limited evidence)

Adaptation of infrastructure should be undertaken within the context of the built form (Markolf et al., 2018; Dawson, 2015).

SM6.3.3.1.12 Economic feasibility: unknown (low agreement, limited evidence)

Major transformation is likely to be expensive, but the overall cost-effectiveness is unclear.

SM6.3.3.1.13 Mitigation co-benefit: positive moderate (medium agreement, medium evidence)

Reconfiguration of built form can offer substantial mitigation benefits by altering long-term demand (Lohrey and Creutzig, 2016; Li et al., 2018), though construction activities are typically energy intensive (Bai et al., 2018; Seto et al., 2016).

SM6.3.3.1.14 Targets reducing poverty and marginalisation: negative moderate (low agreement, limited evidence)

Adaptation through relocation of urban poor at risk populations has been observed to severely undermine individual well-being and livelihoods (Arnall, 2019).

SM6.3.3.1.15 Inclusive and locally accountable: positive small (low agreement, limited evidence)

Urban form is linked to accessibility (Rode et al., 2017; Fried et al., 2020) which is important for some aspects of inclusion.

SM6.3.3.1.16 Social transformation: negative moderate (low agreement, limited evidence)

Changes in built form made in the name of reducing flood exposure is a key mechanism for avoiding future exposure. Immediate consequences can be the stranding of assets. Where low-income residential settlements are forced to relocate, this can lead to the transfer of valuable land ownership and use rights away from poorer to richer residents, and from informal and social housing to private ownership undermining transformative adaptation (Shi et al., 2016).

SM6.3.3.1.17 Ecological transformation: positive moderate (medium agreement, medium evidence)

Adaptation of built form can provide beneficial green space, ecological corridors and other services (Grafius et al., 2018).

SM6.3.3.2 Housing and Building Design/Function (see Section 6.3.4.2)

SM6.3.3.2.1 Multiple climate hazards: positive high (high agreement, robust evidence)

A range of adaptation options are available to manage multiple climate risks to houses and buildings (van Hooff et al., 2014; Puckett and Gethering, 2019; CCC, 2019).

SM6.3.3.2.2 Reduces systemic vulnerability: positive high (high agreement, robust evidence)

Systemic reduction in vulnerability can be achieved through new building codes and retrofit programmes (Henstra, 2016; Wilkinson et al., 2014).

SM6.3.3.2.3 Reduces new hazard exposure generated: positive high (high agreement, robust evidence)

Well adapted new buildings avoid increasing exposure to climate risks, whilst adaptation of existing buildings reduces exposure and measures such as building scale water storage can reduce hazards locally (Jamali et al., 2020; Webber et al., 2018).

SM6.3.3.2.4 Transfer of risk: negative negligible (medium agreement, medium evidence)

Air conditioning can increase heat emissions into urban areas (Hwang et al., 2020; Kingsborough et al., 2017), but no evidence was found that other actions transfer risks.

SM6.3.3.2.5 Social capital: positive negligible (low agreement, limited evidence)

Building adaptation programmes have the potential to enhance social capital but *limited evidence* exists (Aldrich et al., 2018).

SM6.3.3.2.6 Livelihoods: positive moderate (medium agreement, medium evidence)

Productivity is higher in well-adapted buildings (Day et al., 2019; Kim and Hong, 2020; Hooyberghs et al., 2017).

SM6.3.3.2.7 Health: positive high (high agreement, robust evidence)

Well-adapted buildings protect occupants from death and illness associated with climate extremes (Alam et al., 2016; Taylor et al., 2018).

SM6.3.3.2.8 Ecological: nil (low agreement, limited evidence)

Certain building adaptations, such as green walls and roofs, can provide ecological benefits (Vijayaraghavan, 2016; Mayrand and Clergeau, 2018), no literature was found on non-green infrastructure enabling ecological adaptation.

SM6.3.3.2.9 Flexibility post-deployment: negative moderate (high agreement, robust evidence)

Housing and buildings have a long lifespan, but a number of adaptations can be retrofit (Ürge-Vorsatz et al., 2018; Sandberg et al., 2016; Reyna and Chester, 2015).

SM6.3.3.2.10 Deployable at scale: positive high (high agreement, robust evidence)

Retrofit programmes, or changes in building codes, can be scaled widely (Sandberg et al., 2016; Gouldson et al., 2015).

SM6.3.3.2.11 Benefit to other infrastructure systems adaptation: positive negligible (medium agreement, limited evidence)

Buildings are end users of infrastructure services so some adaptations would not provide benefits to the resilience of other services; actions that reduce in-building demand, for example water consumption, reduces pressure on that infrastructure service (Golz et al., 2019; CCC, 2019).

SM6.3.3.2.12 Economic feasibility: positive moderate (medium agreement, medium evidence)

Well-adapted design is a cost-effective option, retrofit can be more expensive depending on the technologies used (Bastidas-Arteaga and Stewart, 2019; Aerts, 2018).

SM6.3.3.2.13 Mitigation co-benefits: positive high (medium agreement, medium evidence)

Construction-based adaptation requires energy (Bai et al., 2018), but many actions, for example reducing water use and lower energy consumption (Golz et al., 2019; Sharifi, 2020).

SM6.3.3.2.14 Targets reducing poverty and marginalisation: negative moderate (medium agreement, medium evidence)

Retrofitting of residential properties for heatwave adaptation has been associated with private property owners and higher value rental properties, creating inequality (Schünemann et al., 2020).

SM6.3.3.2.15 Inclusive and locally accountable: positive small (medium agreement, medium evidence)

Building adaptation can be inclusive when it includes training (Yakubu, 2019) and locally accountable when part of local design processes (Matopoulos et al., 2014).

SM6.3.3.2.16 Social transformation: negative moderate (medium agreement, medium evidence)

Adaptation of social housing could provide a mechanism for enhanced welfare and re-distributional equity. The limited data on adaptation in social housing shows that this lags behind adaptation of private property so undermining transformation (Kenna, 2008). Similar failure for comprehensive addressing of marginality in upgrading of slum housing also misses opportunities for transformation (Ajibade and McBean, 2014).

SM6.3.3.2.17 Ecological transformation: positive small (medium agreement, medium evidence)

Some adaptation options for buildings can support ecological transformation when undertaken together with nature-based solutions, for example large-scale deployment of green roofs to create ecological corridors (Vijayaraghavan, 2016; Mayrand and Clergeau, 2018).

SM6.3.3.3 ICT (see Section 6.3.4.3)

SM6.3.3.3.1 Multiple climate hazards: positive high (high agreement, robust evidence)

A range of adaptation options are available for ICT systems to manage flood, heat and wind risks (Sakano et al., 2016; Fu et al., 2016).

SM6.3.3.3.2 Reduces systemic vulnerability: positive high (high agreement, medium evidence)

Systemic reduction in vulnerability can be achieved through network-wide measures such as topology design and new standards (Fu et al., 2017; Val et al., 2019).

SM6.3.3.3.3 Reduces new hazard exposure generated: nil (low agreement, limited evidence)

No reported evidence found that suggests ICT adaptation changes behaviour that reduces exposure (though the presence of ICT can provide benefits).

SM6.3.3.3.4 Transfer of risk: nil (low agreement, limited evidence)

No reported evidence found that suggests ICT adaptation transfers risks.

SM6.3.3.3.5 Social capital: positive moderate (high agreement, robust evidence)

ICT can be rapidly deployed to support disaster management and thereby acts as an adaptation action in its own right (Eakin et al., 2015; Heeks and Ospina, 2019; Haworth et al., 2018; Imam et al., 2017).

SM6.3.3.3.6 Livelihoods: positive moderate (high agreement, medium evidence)

Well-adapted ICT infrastructure supports economic growth and offers opportunities for business, especially in remote areas (Veknatesh et al., 2017) and for revenue generation in 'smart' cities (Angelidou, 2015).

SM6.3.3.3.7 Health: nil (low agreement, limited evidence)

No reported evidence found that suggests ICT adaptation provides indirect health benefits.

SM6.3.3.3.8 Ecological: nil (low agreement, limited evidence)

No reported evidence found that suggests ICT adaptation provides indirect ecosystem benefits.

SM6.3.3.3.9 Flexibility post-deployment: positive high (high agreement, robust evidence)

With the exception of important fixed assets such as data centres and exchanges, ICT infrastructure is mostly very flexible, upgrade cycles are short compared to other infrastructure enabling adaptation to occur quickly and cost-effectively as part of regular upgrades (Sakano et al., 2016; Val et al., 2019).

SM6.3.3.3.10 Deployable at scale: positive high (high agreement, medium evidence)

With robust standards and regulation, adaptation is deployable at scale (Fu et al., 2016).

SM6.3.3.3.11 Benefit to other infrastructure systems adaptation: positive high (high agreement, robust evidence)

ICT increasingly underpins and enables other infrastructure sectors and the built environment (Norman, 2018; Maki et al., 2019). Adaptation therefore provides wide benefits.

SM6.3.3.3.12 Economic feasibility: positive high (high agreement, medium evidence)

High natural turnover of ICT assets allows adaptation to be worked into asset management cycles and the high commercial return makes ICT adaptation typically affordable (Sakano et al., 2016). Infrastructure adaptation typically provides a good benefit-to-cost ratio (GCA, 2019; Watkiss et al., 2021).

SM6.3.3.3.13 Mitigation co-benefit: positive moderate (medium agreement, medium evidence)

Smart infrastructure typically enables more efficient operation and reduced energy use and GHG emissions (Ismagilova et al., 2019). However, ICT systems are a fast-growing source of global emissions (Anser et al., 2021; Belkhir and Elmeligi, 2018).

SM6.3.3.3.14 Targets reducing poverty and marginalisation: positive moderate (low agreement, medium evidence)

A well-adapted communication infrastructure can create a digital divide but can also reduce marginalisation and provide economic benefits when deployed widely and with appropriate support and training for uptake (Eakin et al., 2015; Heeks and Ospina, 2019; Haworth et al., 2018; Imam et al., 2017).

SM6.3.3.3.15 Inclusive and locally accountable: positive moderate (low agreement, medium evidence)

Can support community resilience programmes and improve transparency (Laspidou, 2014; Devkota and Phuyal, 2018; Panda et al., 2019), but also spread misinformation and create a digital divide (Haworth et al., 2018; Coletta and Kitchin, 2017; Leszczynski, 2016).

SM6.3.3.3.16 Social Transformation: positive moderate (medium agreement, medium evidence)

Well adapted, resilient, ICT infrastructure enables processes of economic and social transformation (in rural areas in particular), for example, to provide continued economic opportunities for female entrepreneurs (Venkatesh et al., 2017) and alternative service delivery models for other infrastructure systems (Angelidou, 2015; Richter et al., 2017).

SM6.3.3.3.17 Ecological transformation: nil (low agreement, limited evidence)

No evidence found that ICT infrastructure supports ecological transformation.

SM6.3.3.4 Energy Infrastructure (see Section 6.3.4.4)

SM6.3.3.4.1 Multiple climate hazards: positive high (high agreement, robust evidence)

A range of adaptation options are available for energy systems to manage flood, heat, wind and subsidence risks (Cronin et al., 2018).

SM6.3.3.4.2 Reduces systemic vulnerability: positive high (high agreement, medium evidence)

Systemic reduction in vulnerability can be achieved through network-wide measures such as topology design and new standards (Fu et al., 2014; Panteli et al., 2017).

SM6.3.3.4.3 Reduces new hazard exposure generated: nil (low agreement, limited evidence)

No reported evidence found that suggests energy adaptation changes behaviour that reduces exposure.

SM6.3.3.4.4 Transfer of risk: nil (low agreement, limited evidence)

No reported evidence found that suggests energy adaptation transfers risks.

SM6.3.3.4.5 Social capital: positive small (high agreement, limited evidence)

Community adaptation actions can build social capital (Ghanem et al., 2016; Brummer, 2018; Radtke, 2014).

SM6.3.3.4.6 Livelihoods: positive high (high agreement, robust evidence)

Energy infrastructure is crucial to support economic activity and livelihoods (Biggs et al., 2015; Fankhauser and Stern, 2016).

SM6.3.3.4.7 Health: nil (low agreement, limited evidence)

No reported evidence found that suggests energy adaptation provides indirect health benefits.

SM6.3.3.4.8 Ecological: nil (low agreement, limited evidence)

No reported evidence found that suggests energy adaptation provides indirect ecosystem benefits.

SM6.3.3.4.9 Flexibility post-deployment: negative moderate (high agreement, medium evidence)

Energy infrastructure typically has relatively low flexibility once installed (Fu et al., 2017).

SM6.3.3.4.10 Deployable at scale: positive moderate (medium agreement, medium evidence)

With robust standards and regulation, adaptation is deployable at scale (ENA, 2015).

SM6.3.3.4.11 Benefit to other infrastructure systems adaptation: positive high (high agreement, robust evidence)

Energy increasingly underpins and enables other infrastructure sectors and the built environment (Dawson et al., 2018; Pescaroli and Alexander, 2016; Kong et al., 2019). Adaptation therefore provides wide benefits.

SM6.3.3.4.12 Economic feasibility: positive high (medium agreement, medium evidence)

Building in resilience from the outset is far more cost-effective than retrofit, but infrastructure adaptation typically provides a good benefit-to-cost ratio (GCA, 2019; Watkiss et al., 2021).

SM6.3.3.4.13 Mitigation co-benefit: positive high (high agreement, robust evidence)

Well-adapted low carbon energy systems are crucial to underpin mitigation efforts (Kemp, 2017; Feldpausch-Parker et al., 2018).

SM6.3.3.4.14 Targets reducing poverty and marginalisation: positive moderate (medium agreement, medium evidence)

A well-adapted energy system helps reduce poverty and can reduce marginalisation if equitably delivered (Bulkelely et al., 2014; Wamsler and Raggers, 2018).

SM6.3.3.4.15 Inclusive and locally accountable: positive moderate (medium agreement, medium evidence)

A well-adapted energy system can support community resilience and accountability depending on the service delivery model (Ghanem et al., 2016; Sharifi and Yamagata, 2016). Although top-down targets can sometimes inhibit local action (Wu et al., 2017).

SM6.3.3.4.16 Social transformation: nil (low agreement, limited evidence)

No evidence found that adaptation of energy infrastructure (as opposed to choices about the original infrastructure) supports social transformation.

SM6.3.3.4.17 Ecological transformation: nil (low agreement, limited evidence)

No evidence found that adaptation of energy infrastructure supports ecological transformation.

SM6.3.3.5 Transport (see Section 6.3.4.5)

SM6.3.3.5.1 Multiple climate hazards: positive high (high agreement, robust evidence)

A range of adaptation options are available for transport systems to manage flood, heat, wind and geohazard risks (Doll et al., 2014; Forzieri et al., 2018).

SM6.3.3.5.2 Reduces systemic vulnerability: positive high (high agreement, medium evidence)

Systemic reduction in vulnerability can be achieved through network-wide measures such as topology design and new standards (Doll et al., 2014; Koks et al., 2019).

SM6.3.3.5.3 Reduces new hazard exposure generated: negative small (low agreement, limited evidence)

Adaptation increases the reliability of transport infrastructure, which can increase the use of particular modes (Wong et al., 2017) or particular assets (e.g., airports; Yesudian and Dawson, 2021), potentially increasing exposure.

SM6.3.3.5.4 Transfer of risk: nil (low agreement, limited evidence)

Some transport adaptations, for example the use of tunnels as temporary water storage, provide wider benefits to the built environment (Soon et al., 2017).

SM6.3.3.5.5 Social capital: positive small (high agreement, limited evidence)

The relationship between social capital and transport can be positive and negative (Schwanen, 2015), with approaches such as transit-oriented urban development helping to develop social capital (Kamruzzaman et al., 2014).

SM6.3.3.5.6 Livelihoods: positive high (high agreement, robust evidence)

Transport infrastructure is crucial to support economic growth and livelihoods (Farhadi, 2015; Saidi et al., 2018).

SM6.3.3.5.7 Health: nil (low agreement, limited evidence)

Ensuring active transport infrastructure if well adapted improves uptake which has health benefits (Wong et al., 2017; Winters et al., 2017).

SM6.3.3.5.8 Ecological: negative small (low agreement, limited evidence)

Overall adaptation to existing infrastructure has a nil or negative impact on ecology through standard construction impacts. This could be extended if new roads, railways, etc., were built as adaptations to climate change and its landscape effects. Some transport adaptation interventions, such as creation of green corridors, can provide ecological benefits, or mitigate the negative ecological impacts (Davies et al., 2014).

SM6.3.3.5.9 Flexibility post-deployment: negative high (high agreement, medium evidence)

The physical elements of the transport infrastructure system typically have low flexibility once installed (Ürge-Vorsatz et al., 2018)), although new technologies can enable this to be used in different ways (Suatmadi et al., 2019; Vanderschuren and Baufeldt, 2018).

SM6.3.3.5.10 Deployable at scale: positive moderate (medium agreement, medium evidence)

With robust standards and regulation adaptation is deployable at scale (Colin et al., 2016; Quinn et al., 2018).

SM6.3.3.5.11 Benefit to other infrastructure systems adaptation: positive moderate (medium agreement, medium evidence)

Accessibility and movement of goods is important to ensure operation of other infrastructures (Hossain et al., 2020; Haraguchi and Kim, 2016; Pregnolato et al., 2016).

SM6.3.3.5.12 Economic feasibility: positive high (medium agreement, medium evidence)

Building in resilience from the outset is far more cost-effective than retrofit (GCA, 2019; Watkiss et al., 2021).

SM6.3.3.5.13 Mitigation co-benefit: positive small (medium agreement, limited evidence)

Some adaptation activities may benefit mitigation efforts by influencing demand or making low-carbon infrastructure such as electric vehicle charging stations more resilient (Shaheen et al., 2019; Costa et al., 2018).

SM6.3.3.5.14 Targets reducing poverty and marginalisation: positive moderate (medium agreement, medium evidence)

A well-adapted transport system helps reduce poverty and can reduce marginalisation if equitably delivered (Kamruzzaman et al., 2014; Schwanen, 2015; Mazumdar et al., 2018).

SM6.3.3.5.15 Inclusive and locally accountable: positive moderate (medium agreement, medium evidence)

A well-adapted transport system can support community resilience and accountability depending on the service delivery model (Mattioli and Colleoni, 2016).

SM6.3.3.5.16 Social transformation: nil (low agreement, limited evidence)

No evidence found that adaptation of transport infrastructure (as opposed to choices about the original infrastructure) supports social transformation.

SM6.3.3.5.17 Ecological transformation: nil (low agreement, limited evidence)

Adaptation of transport infrastructure can support ecological transformation if incorporated as part of the design (Davies et al., 2014).

SM6.3.3.6 Water and Sanitation (see Section 6.3.4.6)

SM6.3.3.6.1 Multiple climate hazards: positive high (high agreement, robust evidence)

A range of adaptation options are available for water and sanitation systems to manage flood, heat and subsidence risks (Dirwai et al., 2021; Wang et al., 2018).

SM6.3.3.6.2 Reduces systemic vulnerability: positive moderate (high agreement, limited evidence)

Systemic reduction in vulnerability can be achieved through network-wide measures such as topology design and new standards (Campos and Darch, 2015; Ives et al., 2018).

SM6.3.3.6.3 Reduces new hazard exposure generated: negative small (medium agreement, medium evidence)

Adaptation can improve availability and reliability of water resources, in some instances this can increase demand for resources (Wang et al., 2016).

SM6.3.3.6.4 Transfer of risk: positive small (low agreement, medium evidence)

Adaptation measures can alter flows, potentially displacing risks (Olmstead, 2014).

SM6.3.3.6.5 Social capital: positive moderate (high agreement, limited evidence)

Community adaptation actions can build social capital and improve health outcomes (Bisung et al., 2014; Dean et al., 2016; Amaris et al., 2021)

SM6.3.3.6.6 Livelihoods: positive high (high agreement, robust evidence)

Water and sanitation infrastructure are crucial to support economic growth and livelihoods, nearly four out of five jobs are dependent on water (UN, 2016).

SM6.3.3.6.7 Health: positive high (high agreement, robust evidence)

Well-adapted water and sanitation systems are crucial to public health (Howard et al., 2016).

SM6.3.3.6.8 Ecological: positive moderate (high agreement, robust evidence)

Actions to improve water quality and reduce water abstraction support ecological services (Miller and Hutchins, 2017; Jeppesen et al., 2015).

SM6.3.3.6.9 Flexibility post-deployment: negative high (high agreement, medium evidence)

Water and sanitation physical infrastructure typically have low flexibility once installed (Walker et al., 2017), although some more flexible alternatives are emerging (Spiller et al., 2015).

SM6.3.3.6.10 Deployable at scale: positive moderate (medium agreement, medium evidence)

With robust standards and regulation, adaptation is deployable at scale (Bouabid and Louis, 2015; Dasgupta et al., 2021).

SM6.3.3.6.11 Benefit to other infrastructure systems adaptation: positive moderate (high agreement, robust evidence)

Improved drainage reduces flood risk to other infrastructures (Yazdanfar and Sharma, 2015; Hoang and Fenner, 2016). Managing water consumption helps ensure sufficient water for energy generation cooling (van Vliet, et al., 2016; Byers et al., 2016).

SM6.3.3.6.12 Economic feasibility: positive high (medium agreement, medium evidence)

Building in resilience from the outset is far more cost-effective than retrofit, but infrastructure adaptation typically provides a good benefit-to-cost ratio (GCA, 2019; Watkiss et al., 2021).

SM6.3.3.6.13 Mitigation co-benefit: positive moderate (high agreement, medium evidence)

Adaptation to reduce water consumption and wastewater production lowers energy use (Wa'el et al., 2017; Hamiche et al., 2016).

SM6.3.3.6.14 Targets reducing poverty and marginalisation: positive high (medium agreement, robust evidence)

A well-adapted water and sanitation system is essential to reduce marginalisation and poverty (Howard et al., 2016; Duncker, 2019).

SM6.3.3.6.15 Inclusive and locally accountable: positive moderate (medium agreement, medium evidence)

A well-adapted water and sanitation system can support community resilience and accountability depending on the service delivery model (Duncker, 2019; Schrecongost et al., 2020).

SM6.3.3.6.16 Social transformation: nil (low agreement, limited evidence)

No evidence found that adaptation of water and sanitation infrastructure (as opposed to choices about the original infrastructure) supports social transformation.

SM6.3.3.6.17 Ecological transformation: positive moderate (high agreement, robust evidence)

Well-adapted water and sanitation systems have significant ecological benefits (Miller and Hutchins, 2017; Jeppesen et al., 2015).

SM6.3.3.7 Flood Management (see Section 6.3.4.7)

SM6.3.3.7.1 Multiple climate hazards: positive small (high agreement, robust evidence)

Physical flood management infrastructure interventions do not typically address multiple climate hazards (Sayers et al., 2015).

SM6.3.3.7.2 Reduces systemic vulnerability: positive moderate (high agreement, medium evidence)

Application of standards, flood warning and education programmes can enhance resilience (Byun and Hamlet, 2020; Cools et al., 2016; Williams et al., 2017) but many education programmes have limited effectiveness (Osberghaus and Hinrichs, 2021).

SM6.3.3.7.3 Reduces new hazard exposure generated: negative small (high agreement, medium evidence)

Flood defences can create confidence that leads to more construction behind them, increasing residual risk (Miller et al., 2019; Ludy and Kondolf, 2012).

SM6.3.3.7.4 Transfer of risk: negative moderate (high agreement, robust evidence)

Flood defence infrastructure can alter river flow and sediment behaviour downstream, which can increase downstream risks (Kondolf et al., 2014; Thaler and Hartmann, 2016).

SM6.3.3.7.5 Social capital: positive moderate (medium agreement, medium evidence)

Flood warning and education programmes can contribute towards community social capital and improve uptake of some measures (Cools et al., 2016; Williams et al., 2017; Dittrich et al., 2016).

SM6.3.3.7.6 Livelihoods: positive high (high agreement, robust evidence)

Flood management adaptation reduces disruption of key services, economy and livelihoods (Pant et al., 2018; Ward et al., 2017).

SM6.3.3.7.7 Health: positive high (high agreement, robust evidence)

Flood management adaptation reduces risks to lives and public health (Hu et al., 2018; Venkataramanan et al., 2019).

SM6.3.3.7.8 Ecological: negative moderate (medium agreement, medium evidence)

Grey infrastructure, unless part of a hybrid grey–green solution, does not usually offer ecological benefits (Kok et al., 2021; Scheres and Schüttrumpf, 2019; Sayers et al., 2015).

SM6.3.3.7.9 Flexibility post-deployment: negative negligible (high agreement, medium evidence)

Physical flood management infrastructure typically has low flexibility once installed (Octavianti and Charles, 2019), although flexible designs and adaptive pathways are emerging (Anvarifar et al., 2016; Kapetas and Fenner, 2020).

SM6.3.3.7.10 Deployable at scale: positive high (high agreement, robust evidence)

Flood management infrastructure can be deployed at significant spatial scale, with examples at city, regional and national scales (de Moel et al., 2015).

SM6.3.3.7.11 Benefit to other infrastructure systems adaptation: positive high (high agreement, robust evidence)

Protection is provided to other infrastructure in the floodplain (Pant et al., 2018).

SM6.3.3.7.12 Economic feasibility: positive moderate (high agreement, robust evidence)

Globally, benefits of flood management outweigh costs (Ward et al., 2017). For large settlements, flood management infrastructure is usually highly cost-effective, but increasingly less so for small towns and villages (Tiggeloven and Moel, 2020).

SM6.3.3.7.13 Mitigation co-benefit: negative negligible (high agreement, limited evidence)

Construction usually has a carbon footprint (though very small as a proportion of global emissions) (Beber et al., 2020).

SM6.3.3.7.14 Targets reducing poverty and marginalisation: negative moderate (medium agreement, medium evidence)

Although flood management infrastructure can provide universal protection, evidence shows poorer and more vulnerable communities typically face higher flood risks and lower access to individual property measures (Sayers et al., 2018; van Bavel et al., 2018).

SM6.3.3.7.15 Inclusive and locally accountable: negative negligible (low agreement, medium evidence)

Many large-scale schemes are reliant on central government funding and decision making criteria, but participatory processes can better engage communities and improve local accountability (Garvey and Paavola, 2021; Everard, 2015.

SM6.3.3.7.16 Social transformation: nil (low agreement, limited evidence)

No evidence found that adaptation of physical flood management infrastructure supports social transformation.

SM6.3.3.7.17 Ecological transformation: negative small (medium agreement, limited evidence)

Grey infrastructure, unless part of a hybrid grey–green solution, does not usually offer opportunity to support ecological transformation (Kok et al., 2021; Scheres and Schüttrumpf, 2019; Sayers et al., 2015).

SM6.3.3.8 Coastal Management (see Section 6.3.4.8)

SM6.3.3.8.1 Multiple climate hazards: positive small (high agreement, robust evidence)

Physical coastal management infrastructure interventions do not typically address multiple climate hazards (Sayers et al., 2015), although some can provide multiple socioeconomic benefits (Kothuis and Kok, 2017; Anvarifar et al., 2017).

SM6.3.3.8.2 Reduces systemic vulnerability: positive moderate (high agreement, medium evidence)

Physical infrastructure reduces the likelihood of flooding for the area it protects, whilst flood warning, education programmes and community relocation support can reduce vulnerability (Matyas and Pelling, 2015; Sayers et al., 2015).

SM6.3.3.8.3 Reduces new hazard exposure generated: negative small (high agreement, medium evidence)

Coastal management can create confidence that leads to more construction behind them, increasing residual risk (Miller et al., 2019; Ludy and Kondolf, 2012).

SM6.3.3.8.4 Transfer of risk: negative moderate (high agreement, robust evidence)

Coastal management infrastructure can alter coastal sediment movements and degrade ecosystems, which can increase flood and erosion risks elsewhere (Wang et al., 2018a; Dawson, 2015; Nicholls et al., 2015).

SM6.3.3.8.5 Social capital: positive moderate (medium agreement, medium evidence)

Understanding and enhancing social capital can improve the effectiveness and uptake of coastal management infrastructure; physical infrastructure adaptation tends not to contribute towards social capital unless part of a wider programme of coastal flood warning, education programmes and community relocation (Matyas and Pelling, 2015; Triyanti et al., 2017; Rojas et al., 2014; Petzold and Ratter, 2015).

SM6.3.3.8.6 Livelihoods: positive high (high agreement, robust evidence)

Coastal management infrastructure adaptation reduces disruption of key services, economy and livelihoods (Shughrue and Seto, 2018; Yesudian and Dawson, 2021; Tiggeloven and Moel, 2020).

SM6.3.3.8.7 Health: positive high (high agreement, robust evidence)

Coastal management infrastructure adaptation reduces risks to lives and public health from coastal erosion and flooding (Brown et al., 2018; Kulp and Strauss, 2019; Haasnoot et al., 2021).

SM6.3.3.8.8 Ecological: negative moderate (medium agreement, medium evidence)

Physical infrastructure typically has negligible or negative ecological benefits (Renaud et al., 2015), unless part of a hybrid soft engineering or nature-based engineering solution (Schoonees et al., 2019; Grimm et al., 2016; Depietri and McPhearson, 2017; Morris et al., 2018).

SM6.3.3.8.9 Flexibility post-deployment: negative negligible (high agreement, medium evidence)

Physical coastal management infrastructure typically has low flexibility once installed, although some more flexible designs have been proposed (Sayers et al., 2015; Kothuis and Kok, 2017; Anvarifar et al., 2016), however adaptation pathways that might include physical protection offer more flexible strategies to coastal management (Haasnoot et al., 2019).

SM6.3.3.8.10 Deployable at scale: positive high (high agreement, robust evidence)

Coastal management infrastructure can be deployed at significant spatial scale, with examples at city, regional and national scales (Scussolini et al., 2016).

SM6.3.3.8.11 Benefit to other infrastructure systems adaptation: positive high (high agreement, robust evidence)

Protection is provided to other infrastructure at risk from flooding and erosion (Koks et al., 2019; Brown et al., 2014).

SM6.3.3.8.12 Economic feasibility: positive moderate (high agreement, robust evidence)

Globally, benefits of coastal management outweigh costs (Hinkel et al., 2014; Tiggeloven and Moel, 2020). For large settlements, coastal flood and erosion management infrastructure is usually highly cost-effective, but increasingly less so for small towns and villages (Nicholls et al., 2015).

SM6.3.3.8.13 Mitigation co-benefit: negative negligible (high agreement, limited evidence)

Construction usually has a carbon footprint (though very small as a proportion of global emissions) (Beber et al., 2020).

SM6.3.3.8.14 Targets reducing poverty and marginalisation: negative moderate (medium agreement, medium evidence)

Although coastal management infrastructure can provide universal protection, evidence shows poorer and more vulnerable communities typically face higher risks, and smaller communities are often unable to demonstrate cost-effectiveness (Pelling and Garschagen, 2019; Clément et al., 2015; Fletcher et al., 2016).

SM6.3.3.8.15 Inclusive and locally accountable: negative negligible (low agreement, medium evidence)

Many large-scale schemes are reliant on central government funding and decision making criteria, but participatory processes can better engage communities, provide local accountability and co-benefits (Matyas and Pelling, 2015; Triyanti et al., 2017; Rojas et al., 2014; Petzold and Ratter, 2015; Kothuis and Kok, 2017; Anvarifar et al., 2016).

SM6.3.3.8.16 Social transformation: positive small (low agreement, limited evidence)

No evidence found that adaptation of physical coastal management infrastructure supports social transformation unless part of a wider capacity building programme (Matyas and Pelling, 2015; Triyanti et al., 2017; Rojas et al., 2014; Petzold and Ratter, 2015).

SM6.3.3.8.17 Ecological transformation: negative small (medium agreement, limited evidence)

Physical coastal management infrastructure, unless part of a hybrid soft engineering or green infrastructure solution, does not usually offer opportunity to support ecological transformation (Schoonees et al., 2019; Grimm et al., 2016; Depietri and McPhearson, 2017; Morris et al., 2018).

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