Environmental Science and Policy 136 (2022) 599–608

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

An approach to assess the world's potential for disaster risk reduction through nature-based solutions

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ARTICLE INFO

Keywords:
Nature-based solutions
Ecosystem-based Adaptation
Natural capital
Indicator framework
Climate change risk
Cluster analysis

ABSTRACT

Nature-based Solutions (NBS) have been increasingly advocated as means of achieving a greener and sustainable future. Although discussion on the definition, scale and applicability of NBS in country and city-level agendas are ongoing, NBS have received less attention in terms of them supporting country-level approaches to Disaster Risk Reduction (DRR). This paper uses a series of indicators reflecting national capability and national necessity for NBS as a means to support DRR activities. Using both Principal Components Analysis and Cluster Analysis results show that of a total of 178 countries, two groups emerge; with countries in one group showing high levels of both national capability and necessity for NBS. Such countries are also found to be around 23 % more likely to be currently implementing disaster risk reduction actions than countries with lower capability and necessity scores, showing that NBS are actively supporting DRR activities around the world. Such countries are a mixture of Global South and North countries while showing no statistical significant differences with respect to socio-economic characteristics, indicating that NBS can be equitable means of achieving potential synergies between DRR-reducing NBS and grey infrastructure projects for climate change adaptation measures.

1. Introduction

Nature-based Solutions (NBS) are seeing a surge in the academic and policy agendas as arguably low-tech solutions to persistent and- often 'wicked' (Duckett et al., 2016)- socio-ecological problems (Albert et al., 2017). There are varying definitions of NBS, but the most ambitious interpretations entail a radical reappraisal of our way of relating to and managing our environment, underpinned by a paradigm shift by which we need to 'work with nature' in an effort to maximise society's welfare instead of pining the 'human' against the 'natural' (Bark et al., 2021). As a concept, NBS can be considered an inheritor of approaches such as ecological engineering (Odum and Odum, 2003) and ecological restoration (Society of Ecological Restoration SER International Science, 2004) while it has developed alongside Ecosystem-based Adaptation (EbA) (Faivre et al., 2017). Such approaches dominated the discussion around the topic of conserving nature in the late 2000 s and NBS were further clarified in terms of typologies they include in the period 2014–2019 (Cohen-Shacham et al., 2019).

NBS have most notably gained traction in the policy discourse as mechanisms for mitigation of and adaptation to climate change. Over sixty percent of the Nationally Determined Contributions of countries that signed the Paris Agreement of 2015 identified EbA or NBS measures as means to achieve climate change adaptation and mitigation (Seddon et al., 2019). Just four years later, the Green Deal published by the European Commission explicitly mentions NBS as lasting climate change adaptation and mitigation measures involving both terrestrial and marine ecosystems (European Commission, 2020). Similarly, other references to NBS' use to combat climate change and reduce environmental degradation can be found in high level political agendas in the United States, as for example in the executive order[1] signed by President Joe Bidden shortly after his election or the 2021′s statement[2] from President Xi Jinping on China's intention to reduce carbon emissions. NBS have also been suggested as an adaptive development mechanisms to achieving a number of UN Sustainable Development Goals (SDGs) (United Nations, 2015).

Countries that spearhead the advocacy for transitioning to NBS

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[1] Available at: https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

[2] Available at: https://www.reuters.com/article/us-china-climatechange/china-pushes-technical-solutions-in-race-to-meet-climate-goals-idUSKBN29I1EA

https://doi.org/10.1016/j.envsci.2022.07.021
Received 17 December 2021; Received in revised form 21 June 2022; Accepted 13 July 2022

(instead of, or at least alongside, traditional, or so-called "grey", infrastructure), do so based on two main arguments. Firstly, NBS are advocated as catalysts in protecting human life and safeguarding its future (Faivre et al., 2017). This is mainly argued on the basis of the potential attributed to NBS in enhancing sustainable urbanisation, restoring degraded ecosystems, developing climate change adaptation and mitigation and improving risk management and resilience (DG Environment, 2015). Secondly, NBS are thought to provide much needed services and benefits at lower capital costs (The Royal Society, 2014), helping to fill the infrastructure gap required to achieve a worldwide carbon-low transition under a 1.5 °C scenario, which has been estimated by the Intergovernmental Panel on Climate Change (IPCC), 2018 at between USD1.6 trillion to USD 3.8 trillion for the period 2016–2050.

This policy interest is growing alongside increasing academic debates on NBS according to both regional and global-scale targets (Cohen-Shacham et al., 2019) and how NBS can or should be categorised (Eggermont et al., 2015). Despite this promising start as a 'new' environmental approach, there has so far been in the global conversation on NBS, little attention paid to what is the potential for them to become mainstream or if NBS are likely to remain a niche solution to a limited set of site or infrastructure specific improvements. A rapid rise followed by a fall would not be new in the environmental and conservation world. Leisher (2015) actually found that it is common, in the conservation sphere, to have once prominent approaches abandoned for the "next new thing" after just one decade. Whether NBS are likely to transition from 'just' being supported in research and policy documents and adopted scatteredly, to being adopted and implemented widely across countries and cities as the predominant approach represents the next environmental research frontier.

A number of investments from non-governmental organisations, investment banks and governments have been issued to finance projects that involve NBS. There has been a 37 % increase in NBS-related investments in 2018 compared to 2013 from public and private actors combined, totalling USD546 billion (Buchner et al., 2019). Some countries such as those of the EU, North America and East Asia have been consistently advancing the use of NBS within city and rural planning more than other countries (Escobedo et al., 2019). The 2013 EU strategy on climate change adaptation explicitly linked Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) (European Commission, 2013) while the EU's 2017 Action Plan for nature, people and the economy (European Commission, 2017) advised towards green infrastructure projects to achieve DRR. Some first inventories in Europe (Oppla, 2021) record 1000 NBS projects in community, city and national-scale applications. A growing body of work has been produced outlining both the requirements for applying NBS and lessons learnt from early stages of NBS implementation in cities and neighbourhoods across the world (Monty et al., 2017) and linking NBS with DRR at the country and city level (Faivre et al., 2018).

We argue that in spite of these investments and the recognised benefits of NBS, the pace of implementation remains cautious and begs the question whether there are sufficiently strong drivers for a transformation in the scale of application to achieve global impact. For example, in July 2020, the UK government announced a £ 5.2 billion long-term plan to tackle flooding, of which only £ 200 million was earmarked for local initiatives including NBS (Government, 2021).

This research sidesteps the question of how to direct funding for NBS implementation and instead attempts to inform the creation of a a) rational system of resource (natural and financial) allocation and b) a quantitative framework analysis. Given the complexity of decisions related to NBS implementation, ranging from differences in biome availability to cultural perceptions, we frame our analysis in terms of risk assessment theory that addresses hazards as circumstances with the potential to cause harm. In particular, we focus on potential harm that could otherwise be avoided by achieving national progress on DRR through NBS. We define risk as the scale of damage due to a specific outcome multiplied by the likelihood of that outcome occurring (Schipper and Pelling, 2006; Davidson et al., 2003). We base our definition for national potential to mainstream NBS as the potential for risk avoidance, adapting the UN definition of disaster risk reduction more broadly, paraphrased here as "The concept and practice of reducing risks through systematic efforts to analyse and manage the causal factors of damage, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events" (UNISDR, 2009). In our framing, NBS are conceptualized as strategies to manage the causes of damage, as a contribution to developing national resilience that captures benefits and manages adverse impacts of future change, by supporting development of national structures of governance, productivity and citizen wellbeing.

We focus on national drivers to reduce DRR vulnerability, which combine risk factors of susceptibility to damage based on geographical location and the sociocultural environment including state of development. Doing so, the focus of this research is coarse and is open to theoretical and empirical improvements. Nevertheless, we propose that this potential to mainstream NBS is influenced by the combination of two categories of development drivers that we refer to as national capability and national necessity. We define drivers of national necessity that scale broadly with the level of risk avoidance that occurs by successfully implementing NBS, following the suggestion of Schipper et al. (2016) that disaster risk reduction should put more emphasis on reducing environmental hazards, e.g., the circumstances with potential to cause harm. We assume that institutional and management practices at the country-level affect national adaptation strategies and actions (Schipper and Pelling, 2006). We consider capability indicators that demonstrate the existence of mechanisms to enable the adoption of NBS as adaptation and mitigation actions to prevent harm from the threats defined by climate change. We consider indicators of necessity that represent exposure to specific threats, or the vulnerability of a country to these threats, where NBS are perceived as offering significant protection against harm. These indicators are explained in detail in the following section. These indicators also inform SDGs 1, 11 and 13, and particularly tasks 1.5, 11.b and 13.1. that deal with addressing disaster risk and increasing climate change resilience and adaptive capacity.

Our approach is rooted in empiricism, using the current knowledge of factors influencing NBS adoption within countries and case-study examples and extending it to country-wide indicators of such potential to achieve DRR. We test our approach by attempting to find similarities between potential drivers for NBS implementation at the national level for 177 countries worldwide and in a subset of 80 countries we further examine whether the conceptualised framework of capability and necessity has a causal effect on the current level of countries' adoption of measures to achieve DRR. We also examine how this extrapolation of information looks in the country and SDG region-level and critically evaluate the framework and discuss limitations in the approach and alternative indicator use. Finally, this paper discusses the need for an analytical decision-making framework for natural and financial capital allocation regarding NBS conceptualisation, funding and implementation.

2. Conceptual approach

2.1. Capability drivers

Reducing disaster risk at the country level is an inherently complicated endeavour, especially when climate change adaptation measures are considered. Issues of determining the appropriate temporal and regional scales, all the way to the countries' knowledge base have shown that DRR requirements do not always meet climate change adaptation requirements (Birkmann and von Teichman, 2010). Achieving DRR has been long advocated to incorporate integrated approaches (Gaillard and Mercer, 2013), local and scientific knowledge (Mercer et al., 2010; Hiwasaki et al., 2014) as well as bottom-up and bottom-down actions

(Gaillard and Mercer, 2013). For such reasons NBS have been promoted both at the local and regional level as parts of an effective approach to DRR (Faivre et al., 2018). Past studies have focused on indicator frameworks incorporating disaster risk (e.g., de Almeida et al., 2016) as well as exposure and sensitivity (Chang et al., 2018). As such, we attempt to focus on a select group of robust indicators[3] and invite further discussion and research around inclusion and exclusion of indicators based on climate change adaptation, mitigation and disaster risk reduction theories, data availability and so on.

We use three indicators to capture national capability drivers: the percentage of forest area a country has (as percentage of total country area), the percentage of country area assigned protected status and the percentage of GDP generated by agriculture, forestry and fisheries. Next we describe and explain the rationale for each of these.

Forest extent reflects favourable climatic conditions to support a country's biome (Cuny et al., 2015) and as such can serve as an indicator of a country's inherent capability for biomass production. Forest extent and appropriate management are considered key components of implementing and mainstreaming NBS (Maes and Jacobs, 2017) and countries aiming for climate change mitigation stand to gain more financially by forests' primary productivity (Mori et al., 2021). For the purpose of this illustration, we then consider the bigger the extent of forests, the higher the capability of a country to implement and adopt NBS.

We consider the designation of protected status to areas as an indication of a country's past and present political resolve to protect and sustain natural capital. Protected areas have been classified as a type of EbA as they provide several ecosystem services whist conserving natural capital (Cohen-Shacham et al., 2019) since ecosystems in protected areas are allowed to function without some threats of degradation from human activities (Dudley et al., 2010). For example, according to UNEP (2019), Europe, a leader area in pioneering the concept and application of NBS, has 18 % of its land territory under the Natura 2000 network of protective status while 10 % of its marine territory is classified as Marine Protected Areas. Globally, only 4.8 % of the world's marine area is under any protected status (Brander et al., 2020). Strict protected status, such as that required for conservation or no-take-zones is enforced in 3 % of Europe's land and in less than 1 % of its marine areas are under strict protection (European Commission, 2020). In terms of marine protected areas, only 2.2 % of all marine areas is designated as no-take areas (Brander et al., 2020). Extent of protected areas is expected to reflect the capability of a country to implement NBS.

We consider the dependency of a country's economy to sectors that themselves rely on natural capital (agriculture, forestry and fisheries) as an indication of a country's natural capital contribution to the economy, captured by their value in commercial markets. Such contribution can also be seen as an expression of a country's ability to withstand demographic transformations that reduce agricultural production, rural land-use changes and growth in agricultural service markets to meet the growing needs of the industry (Mortimore, 2010). Food production in the agricultural, forestry and fishing sectors is dependant of NBS (Maes and Jacobs, 2017) as they support and maintain natural capital flows and stock such as freshwater quantity and quality (Cohen-Shacham et al., 2016). Ideally, if natural capital accounts existed for all countries they would serve as a better indicator for the economic value of natural capital stocks and flows, instead we need to resort to the contribution of the primary sectors as a rough (and admittedly deficient) substitute indicator. NBS also provide job security in these sectors (Faivre et al., 2017), and consequently their production as they are labour-intensive where job mobility away from the sector is limited. Therefore, in our framework, the higher the contribution of these sectors to a country's economic output (measured through the country's Gross Domestic Product), the higher the country's capability to capitalise natural resources related to NBS.

2.2. *Necessity drivers*

Four country-wide indicators were used to capture the national necessity drivers: the average rate of increase of CO_2 emissions, the percentage of population living in urban centres, the percentage of land under threat of inundation and the average yearly economic costs of climate change.

Countries with high CO_2 emissions are considered having higher economic, social and environmental risk from the impacts of climate change (Stern, 2007; Faivre et al., 2017). As they usually involve plant life, NBS have been advocated as tools to combat rising CO_2 emissions (Connop et al., 2016) by taking land under polluting practices and returning them to low-intensity purposes with re-wilding and vegetation (Popp et al., 2014). As CO_2 emissions increase, the necessity of a country to implement and adopt NBS should also increase.

As the majority of the world's population lives in urban centres, NBS implemented in such areas have been found to have multiple benefits, from protecting health by mitigating heat island effects (van den Bosch and Sang, 2017), to protecting from climate change-related flooding (Arnbjerg-Nielsen et al., 2013) and even safeguarding mental well-being (Mitchell et al., 2015), especially during times of isolation as during the COVID-19 crisis (European Commission, 2020). Therefore, in our framework, the higher the urban population in a country, the bigger the necessity for NBS adoption and implementation.

We consider the percentage of a country with elevation under 5 m as an indication of necessity for NBS. As sea-level-rise and extreme weather events intensify with climate change, low-lying areas are under threat of inundation from flooding which can result in mass migration (McMichael et al., 2020) as up to 10 % of the global population lives in low-lying coastal zones (McGranahan et al., 2007). NBS can be a solution as they offer less costly, low-tech coastal resilience benefits by reducing loss of soil by strengthening the health of coastal ecosystems (Narayan et al., 2016; Kalantari et al., 2018) or by reducing floods near waterways (Short et al., 2019). The bigger the extent of such low-lying areas, the higher the need for mitigation.

Finally, we consider the percentage of a country's GDP impacted by climate change events as an indicator of necessity for NBS. NBS have been advocated as means to reduce risk in economies and their assets (European Commission, 2018). Such risk reductions are captured either in the form of avoiding costs for having to restore biodiversity losses or as pure economic benefits from healthy ecosystems that support food provision and coastal protection (European Commission, 2020). The higher the impact, the higher the need for mitigation and adaptation services.

Following from the above description, in total, seven indicators were used which reflect a country's capability to mitigate risk from threats such as climate change and the country's necessity to do so given its exposure to such threats, as per the framework adopted in this research. As we aim to upscale the empirical information from the case-study level literature to a country level we conduct an exploratory data analysis,

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[3] Reviewing the literature and cross referencing publicly available country-wide data sources we collected an initial set of 20 indicators reflecting a variety of potential drivers for NBS implementation such as natural endowments (e.g., renewable freshwater availability), quality of stakeholder engagement and sectoral engagement in NBS implementation and participation (e.g., agricultural land (% of land area)) were considered. PCAs (see Section 4.1) were carried out for this initial set of indicators and indicators large unexplained variances were excluded from the sample. This resulted in retaining 10 indicators (apart from the final 7 indicators, "renewable freshwater resources", "time to start a business" and "private investment in energy" – all conceptualised as capability indicators and sourced from the World bank datahub) which were then analysed using cluster analysis (see approach in Section 4.2). The retained 7 indicators were the maximum number of indicators that allowed for both variability in the cluster (not having clusters with too many or too few observations) and for the ability for meaningful interpretation of retained factors (i.e., allowing for conceptual interpretation).

Table 1
Indicator description and data sources.

Indicator Description	Variable name	SDGs it reflects	Source
Dependent variable			
Score of adoption and implementation of national DRR strategies	*DRR_SCORE*	SDG:1.5.3 SDG: 11.b.1 SDG: 13.1.2	Global SDG Indicators database
Independent variables		**Assumed influence to NBS adoption**	
Forest area, as a % of total country area	*FOREST_AREA*	*↑ % forest, ↑ NBS capability*	World Bank
Terrestrial and marine protected areas, as a % of total country area	*PR_AREA*	*↑ % of PA, ↑ NBS capability*	World Bank
% of value added to GDP from the primary economic sector (*i.e. agriculture, forestry, and fishing)*	*PRIM_SECT_VALUE*	*↑ % of GDP share, ↑ NBS capability*	World Bank
CO^2 emissions (in kilotons)	*EMISSIONS*	*↑ rate of emissions, ↑ the necessity for NBS*	World Bank
Urban population, as the % of the total population	*URB_POP*	*↑ % of urban population, ↑ necessity for NBS*	World Bank
Land area where elevation is below 5 m, as a % of total land area	*LOW_AREA*	*↑ % of low-laying land, ↑ necessity for NBS*	World Bank
Losses per unit GDP due to climate change	*GDP_LOSSES*	*↑ the costs, ↑ the necessity for NBS*	German Watch (2017)
Country-specific variables			**Source**
Gross Domestic Product in Purchasing Power Parity terms	*GDP_PPP*		World Bank
Land size (in sq. km)	*LAND*		World Bank
Percentage of population living below the poverty line	*POVERTY*		World Bank
Fatalities due to climate change	*CLIM_FATAL*		German Watch (2017)
Population of country	*POPUL*		World Bank

through the use of a Principal Component Analysis (PCA) and Cluster Analysis (CA) with the final aim to examine the relationship between drivers for NBS and current adoption of DRR measures.

3. Data and methods

We collected data from public sources, accessible to the both academics and practicioners, such as the World Bank data hub, the Global SDG Indicators database and Eckstein et al. (2017) for the period between 1998 and 2017. The description of the indicators, the rationale behind their use and their assumed influence on NBS adoption with respect to supporting DRR is presented in Table 1 below. The score of adoption and implementation of national DRR strategies (DRR_SCORE) was selected as the best indicator available that approximates the level of adoption of DRR at the national level. In line with the Sendai Framework, this indicator takes values between 0 and 1, with 1 indicating perfect adoption of DRR measures. Data existed only for 88 countries between 2015 and up to 2019 and therefore the latest data available were used for each country. For the indicators of NBS capability (FOREST_AREA,[4] PR_AREA, PRIM_SECT_VALUE) and necessity (EMISSIONS, URB_POP, LOW_AREA, GDP_LOSSES) data were available for more countries. For all independent variables we used data from the World bank apart for the impact on GDP by climate change (GDP_LOSSES) where we used data from *German Watch* (based on data from the insurance provider MunichRe NatCatSERVICE database) in Eckstein et al. (2017) who conducted a global calculation per country of the costs of climate change over a 20-year period, using data from the insurance company *Munich Re's* on the absolute impact of extreme climatic events on a country's GDP. For these seven suggested indicators data were collected for the period between 1998 and 2017, for consistency between the World Bank datasets and Eckstein et al. Countries with missing data or where data were not reported for all seven indicators were eliminated from the analysis. This resulted in having complete data for 178 countries for all seven indicators. A further group of country-specific socio-economic variables were also used to determine whether differences between the results of the cluster analysis would merit any further examination through a regression analysis. These variables were also extracted from the World Bank and Eckstein et al. (2017) and can be seen in the final section of Table 1 and include the Gross Domestic Product (GDP) in Purchasing Power Parity (PPP) terms, land size, population size, percentage of a country's population living below the poverty line and number of fatalities attributed to climate change.

Similar to previous studies that aim to identify groupings of typologies of NBS, we use PCA and CA methods to explore similarities between suggested NBS indicators identify groupings of similar country cases (Zingraff-Hamed et al., 2021; Castellar et al., 2021). One of the common techniques to reduce the complexity of data without reducing the quality of information they provide while enabling multivariate analysis is Principal Component Analysis (de Sousa Mendes and Devós Ganga, 2013). PCA aims to find the maximum variance of the original data through a combination of original variables, without having an underlining explanatory model (Lattin et al., 2003). In the context of this paper this is desirable as we do not know the effect that the suggested capability and necessity drivers have on NBS adoption.

Using the scoring coefficients of the principal components in a Cluster Analysis allowed to group countries that have similar characteristics, given their capability and necessity drivers, while maximizing the differences between different clusters of countries. Employing a CA after the PCA also allowed to reduce the influence that selection of independent variables can have on the regression analysis (Chen et al., 2016) as the suggested framework is inherently dependent on the quality of the indicators selected. Employing such methods to select subsets of variables is also commonly used to facilitate regression analyses (e.g., Abdul-Wahab et al., 2005; Willemen et al., 2007).

In order to determine the appropriate clustering algorithm and number of clusters, the clValid package (Brock et al., 2011) in R was used to compare different clustering methods, namely hierarchical clustering and partitioning such as *k-means* clustering and partitioning around medoids (PAM) clustering. These methods were compared as they are the most common ones with country or region-wide data (e.g., Lechner et al., 2016; Gough, 2001). These methods measure the distance between two observations within a dataset allowing similar observations to be grouped while allowing observations within a group to be as different as possible from the observations of other groups (Karmakar et al., 2019). The minimum shortest point to connect two observations in multi-dimensional space (called the Euclidean distance and the multi-dimensional space is defined by the number of variables available). The algorithm used finds the centre (mean) points of observations in the Euclidean space for the four components with the number of centres defined by the optimal scores of three different internal validation measures. The values for "connectivity" closer to 0 are preferred while "silhouette" values close to 1 are considered to group observations well. Finally, the higher the "Dunn" ratio, the bigger the differences between observations from different clusters, which is preferred (Brock et al., 2011).

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[4] Note that this indicator does not include trees from agricultural production systems and trees in urban parks and gardens.

Table 2
Descriptive statistics of selected indicators.

Variable name	*No. of countries*	*Mean*	*Std. Dev.*	*Min*	*Max*
DRR_SCORE	88	0.62	0.30	0.00	1.00
FOREST_AREA	178	12.83	12.03	0.06	56.48
PR_AREA	178	3.40	8.69	0.00	55.56
PRIM_SECT_VALUE	178	54.72	23.34	10.09	100.00
EMISSIONS	177	11.76	10.96	0.01	55.08
URB_POP	178	159913	668776	9.49	6544623
LOW_AREA	178	31.69	23.67	0.00	98.48
GDP_LOSSES	178	0.59	1.92	0.00	21.21
GDP_PPP	178	15078	17384	625	109783
LAND	178	729582	1996334	0	17100000
POVERTY	178	24	20	0	72
CLIM_FATAL	178	147	650	0	7049
POPUL	178	15078	17384	625	109783

Table 3
Rotated components for the seven indicators.

Variable	Component 1	Component 2	Component 3	Component 4	Unexplained variance
FOREST_AREA		0.796			0.1824
PRIM_SECT_VALUE	-0.680				0.469
PR_AREA		0.494	0.395	-0.310	0.180
EMISSIONS			0.695		0.359
URB_POP	0.681				0.365
LOW_AREA		-0.585			0.268
GDP_LOSSES				0.931	0.093

Table 4
Full list of countries and the groups with the hierarchical clustering method.

Countries	
Group 1 (89 countries)	Afghanistan* , Albania* , Algeria, Angola* , Antigua and Barbuda, Argentina* , Armenia* , Australia* , Austria* , Azerbaijan* , Bahamas, Bahrain, Bangladesh, Barbados* , Belgium, Belize, Benin, Bhutan* , Bolivia, Bosnia and Herzegovina, Botswana* , Brazil, Brunei Darussalam, Bulgaria* , Burkina Faso* , Burundi* , Cabo Verde, Cambodia, Cameroon* , Canada, Central African Republic, Chad, Chile* , China, Colombia* , Comoros* , Congo, Dem. Rep., Congo, Rep., Costa Rica* , Cote d'Ivoire, Croatia, Cyprus, Czech Republic* , Denmark* , Djibouti, Dominica, Dominican Republic, Ecuador* , Egypt, Arab Rep.* , El Salvador, Eritrea, Estonia* , Eswatini* , Fiji, France* , Gabon, Gambia* , Georgia* , Germany* , Ghana, Greece, Grenada, Guatemala* , Guinea, Guinea-Bissau, Guyana, Haiti, Hungary, Iraq* , Italy* , Lao PDR, Madagascar, Mauritania, Mauritius, Morocco* , Netherlands* , Nicaragua, Nigeria, Oman, Papua New Guinea, Qatar* , Saudi Arabia* , Sri Lanka* , Togo* , Tonga, Tunisia, United Kingdom* , Uruguay* , Zambia*
Group 2 (89 countries)	Belarus* , Ethiopia* , Finland* , Honduras, Iceland, India, Indonesia* , Iran, Islamic Rep., Ireland* , Israel, Jamaica, Japan* , Jordan* , Kazakhstan* , Kenya, Kiribati* , Korea, Rep. * , Kuwait* , Kyrgyz Republic* , Latvia, Lebanon* , Lesotho, Liberia, Libya, Lithuania, Luxembourg, Malawi* , Malaysia* , Maldives* , Mali, Malta, Mexico* , Micronesia, Fed. Sts., Moldova, Mongolia* , Mozambique* , Myanmar* , Namibia* , Nepal* , New Zealand* , Niger* , North Macedonia, Norway* , Pakistan* , Panama, Paraguay* , Peru* , Philippines* , Poland* , Portugal* , Puerto Rico, Romania, Russian Federation* , Rwanda, Samoa* , Senegal, Seychelles, Sierra Leone, Singapore, Slovak Republic* , Slovenia* , Solomon Islands, South Africa* , South Sudan, Spain, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, Sudan* , Suriname, Sweden* , Switzerland* , Tajikistan* , Tanzania* , Thailand* , Timor-Leste, Trinidad and Tobago, Turkey* , Tuvalu, Uganda, Ukraine, United Arab Emirates, United States* , Uzbekistan, Vanuatu, Venezuela RB, Vietnam, Yemen, Rep., Zimbabwe*

*Denoting countries reporting a disaster-risk reduction score for SDG indicator 1.5.3

Table 5
Mean values for the standardised four components with hierarchical clustering.

Clusters	Component 1	Component 2	Component 3	Component 4
1 (N = 89)	-1.01	-0.226	-0.130	-0.063
2 (N = 89)	1.01	0.226	0.130	0.063

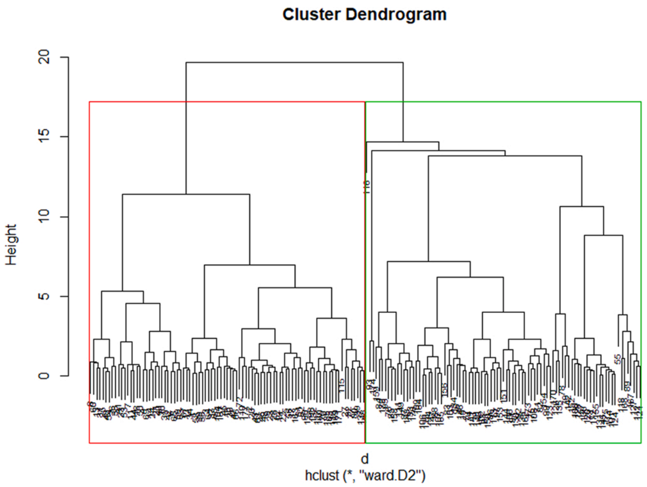

Fig. 1. Final clustering (2 clusters) for the group of 178 countries examined.

Table 6
Distribution of the 2 clusters, by SDG geographical areas.

SDG geographical areas	Cluster 1	Cluster 2	Total number of countries
Africa	31	20	51
Americas	21	14	35
Asia	17	27	44
Europe	16	21	37
Oceania	4	7	11

Table 7
Regression results.

log (DRR_SCORE)	*Coef.*	*Std. Err.*	*p-value*
CLUSTERS	0.2112	0.120	0.082
CONSTANT	-0.808	0.194	0
R-squared	0.038		
Observations	80		

Table A1
Scoring coefficients of the 7 indicator variables for orthogonal varimax rotation.

	Comp1	Comp2	Comp3	Comp4
FOREST_AREA	-0.6796	-0.016	-0.0095	-0.0695
PRIM_SECT_VALUE	0.2253	-0.1864	-0.5847	-0.1166
PR_AREA	0.681	0.0195	0.0076	-0.0226
EMISSIONS	0.0977	0.4938	0.3951	-0.3099
URB_POP	0.1166	-0.2907	0.6952	0.0489
LOW_AREA	0.0032	0.7962	-0.1308	0.1258
GDP_LOSSES	0.02	0.048	0.0389	0.931

Table B1
Optimal number of clusters according to internal validation measures, in bold showing the optimal cluster solution.

Clusters		2	3	4	5	6	7
hierarchical	Connectivity	**2.93**	6.79	9.86	15.30	21.61	42.32
	Dunn	0.57	**0.70**	0.35	0.23	0.20	0.07
	Silhouette	**0.74**	0.66	0.44	0.41	0.28	0.29
kmeans	Connectivity	2.93	6.79	18.93	59.23	58.16	86.22
	Dunn	0.57	0.70	0.08	0.04	0.05	0.05
	Silhouette	0.74	0.66	0.23	0.31	0.32	0.30
pam	Connectivity	47.22	69.53	80.41	89.57	100.94	90.79
	Dunn	0.02	0.02	0.03	0.03	0.02	0.02
	Silhouette	0.28	0.27	0.23	0.23	0.25	0.25

4. Results

The summary statistics for the indicators is presented in Table 2 below. The mean value of the score of adoption of DRR measures is above 0.5 (0.62) but this can be attributed to self-selection as reporting of relevant data used to calculate this indicator is done on a voluntary basis. With respect to the NBS adoption indicators, as data were not reported for some small and resource-deprived countries it is possible that the mean estimates are skewed downwards.

4.1. Principal component analysis

All explanatory variables were normalised based on the mean value and standard deviation, a standard practice when employing methods such as PCA and CA (Lechner et al., 2016). A PCA was carried out in Stata (version 15.1) with a varimax rotation to ensure that principal components are maximally correlated with an individual variable, to facilitate interpretation of the components. The PCA had four components with an Eigen value higher than 1 and the rotated components are presented in Table 3 below. From the relative size of the factors' loadings, the fourth component contains the impacts of climate change on GDP indicator (GDP_LOSSES) while the capability indicators are mainly represented from Components 1 and 2.[5] The necessity indicators are mostly represented by components 3 and 4. Overall, the selected components seem to be explaining most of the variance in the data (see last column of Table 3). The components' scoring coefficients (see Table A1 in the Appendix) were then used for the next step of the cluster analysis.

4.2. Cluster analysis

Using the scoring coefficients from the PCA, a cluster analysis was carried out, a common technique that reduces the dimensions (number of variables) while facilitating the finding of similarities (and maximizing the dissimilarities) between countries (Ding and He, 2004).

From the outputs of clValid, a hierarchical algorithm is suggested by two of the three measures and an optimal number of 2 clusters in Table B1 in the Appendix, according to the "connectivity" and "silhouette" scores performs best in each case. When improving the number of clusters, all three measures deteriorate. The Dunn score suggested a 3-cluster hierarchical approach, but the results included only two countries in the 3rd cluster and therefore was not preferred. The list of countries and the cluster (group) they belong to can be seen in Table 4 below.

The mean values for the four components after a hierarchical clustering with 2 clusters was carried out are presented in Table 5 below. The results clearly group countries that score highly in all necessity and capability indicators in Cluster 2. Ward's minimum variance clustering method identifies the strongest clustering structure and the corresponding dendrogram is plotted in Fig. 1 below.

Clustered countries are presented initially in the five broad geographical areas of the SDGs (Africa, Asia, Americas, Europe and Oceania) for comparison purposes (see Table 6). For the full list of countries in the 2 groups, see Table 5. The countries are evenly distributed both in terms of total number (89 countries each), geographical location and average land size (countries in both groups have, on average, around 730k square kilometres) and the clustering results paint an interesting overall picture.

The first group (Cluster 1) contains more African and Asian countries than Group 2 but it also includes large countries and economies such as China, Brazil, Germany, United Kingdom, France, Australia and Italy. These countries are complemented by several small, landlocked countries from different continents as well as some coastal states and Small Island Developing States (SIDS). Such countries have a combination of limited natural resources, small populations, fewer mitigating policies in place as well as being the least impacted from climate change. The average GDP in PPP terms is slightly smaller in this group than Group 2 (USD 14.3k compared to USD15.8k) as is the average population (37.3 million compared to 46.6 million).

Group 2 (Cluster 2) contains large economies such as the US, India, Russia, Japan and Spain. Also in this group are most of the Scandinavian countries, the largest Southeast Asian countries (Indonesia, Thailand, The Philippines and Vietnam and several small and less well-off European and Balkan countries. Overall, this group has more countries from Asia and Europe than Group 1 (23 % and 10 % more, respectively).

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[5] We have considered the use of renewable freshwater resources as an indicator instead of forest cover and results were inconclusive. In detail, including this indicator instead of forest cover results in 2 clusters with good enough distribution (135 and 43 in Clusters 1 and 2, respectively). Results in the logistic regression were statistically insignificant, though. Also T-tests and Mann-Whitney tests showed no statistical differences between sociodemographic and geographical characteristics and clusters leading to no interpretable results.

Group 2 countries have a higher number of annual climate-related fatalities than Group 1 (1203 versus 734). Group 2 contains less coastal countries than Group 1 (67 coastal countries in Group 2 compared to 78 in Group 1) but both groups have almost the same number of island nations (18 countries in Group 1 and 19 countries in Group 2). Most of the largest Asian countries are in Group 2, with the exception of China, as well as the countries with the highest population (from the top-5 highly populated countries, only one (India) belongs to Group 1).

Several *t*-tests (and a *Mann-Whitney U* test for the non-normally distributed GDP_PPP) were carried out with the country-specific sociodemographic variables of Table 1 and the two clusters to find if there are any statistical differences between the groups. All the tests were non-significant, showing that there are no statistical differences between clusters and socio-economic variables. Conversely, one-way *ANOVA* tests between the country-specific sociodemographic variables and the six SGD geographical areas showed that there are statistical differences at the 1 % level in GDP (GDP_PPP) and population living below the poverty line (POVERTY), showing that the clustering of countries based on their capability and necessity indicators is not driven by geographical or socio-economic differences between them.

4.3. Differences in DRR adoption

To validate the results of the PCA and the CA, we examined whether the suggested indicators can provide an indication of whether countries with similarities in capability and necessity indicators have differences in the current level of adoption of DRR measures. A binary variable denoting a country being in Cluster 1 or 2 and the log-transformed DRR score were used. Only 80 countries were retained for this step from the initial set of 88 countries as 8 countries had reported a DRR score of zero. A *t*-test showed with unequal variances that there are statistical differences in mean DRR score between clusters, at the 10 % level. A one-way ANOVA test (*F(1,78)= 3.11, p-value= 0.082*) showed that the variance of the mean logarithm of the DRR score of the two groups is also not equal. Finally, a univariate regression as shown in Table 7, revealed that a country moving from Cluster 1(37 countries) to Cluster 2 (43 countries) will increase its mean DRR score by 23.6 %. In other words, Group 2 countries have significant differences from Group 1 countries regarding the level of current adoption of DRR measures and their higher scores in the necessity and capability indicators might provide support to existing DRR initiatives through current or future NBS implementation. The model fit is poor, indicating that there are more factors that affect adoption of DRR.

5. Discussion

NBS have seen a rise in application in several advanced economies and have recently presented as means to achieve disaster risk reduction (Calliari et al., 2019). Our analysis provides a first look on how a framework of national capability and necessity indicators of NBS adoption explain current levels of countries' implementation of risk reduction measures while supporting reaching SDG goals 1, 11 and 13. Overall, our approach is an attempt at finding robust-data driven indicators of NBS capability and necessity that also are connecting with reducing vulnerability of climate change risk. By doing so we did not anchor our approach entirely on indicators of reducing risk as means of climate change adaptation or mitigation as NBS implementation focuses on policy and action-focused framework (Frantzeskaki et al., 2020). Further research is therefore required to empirically examine the appropriateness of such indicators to determine notions of national capability and necessity for NBS, both in the context of countries achieving DRR and in the wider context of enhancing biodiversity, achieving net-zero goals and transitioning towards a circular economy.

Our conceptual approach, underpinned by quantitative results from data-driven indicators paints an interesting policy picture. Scoring highly both in capability and necessity indicators of NBS adoption is more likely to exist in countries that have higher scores of adoption of DRR measures. Such countries, represented by Group 2, are a mixture of large, developed and rich countries small, landlocked European and Balkan countries, as well as coastal states and SIDS. Our results show that there is a positive relationship between DRR and possibility of adoption of NBS, with the mean DRR score being 23 % higher in such countries than in countries with lower combined capability and necessity indicators (see Table 7). Additionally, several of these countries have high poverty rates (countries such Mexico, South Sudan and South Africa and several SIDS) which shows that capability and necessity for NBS is not to be seen as a 'luxury' that only rich and powerful can afford but conversely a necessity regardless of the size of an economy. The diverse nature of the countries in that group shows that NBS have indeed the potential to be implemented globally as several countries appear to have the necessary components (such as natural resources and policies to protect the environment) but also the need for the benefits of NBS (land under threat of inundation, people living in urban centres and economic losses due to climate change).

The PCA and CA results as well as the inferential statistics showed that necessity and capability drivers are not dependant on sociodemographic or geographical characteristics. Overall, countries with large economies or countries with a past record in promoting NBS do not appear in one group, such as China, the Netherlands and the US. The results of this work can incentivise countries such as Group 1 countries to increase their capability for NBS through increasing protection of and enhancing the quality of natural resources, through appropriate management frameworks that enable ecosystem management and conservation (Zingraff-Hamed et al., 2020). This is been previously argued for through case-study evidence in these areas (e.g. Cohen-Shacham et al., 2016; Cohen-Shacham et al., 2019) but our analysis offers quantitative evidence, at the country-level, of how NBS capability-increasing actions can support reduction in disaster risk. Nevertheless, our analysis examines the possibility of NBS adoption of countries benefiting from DRR alone. NBS have been associated with achieving wider benefits such as safeguarding its future of human life through sustainable urbanisation and ecosystem restoration (Faivre et al., 2017) and supporting a transition to a circular economy (Faivre et al., 2018).

The analysis shows that high capability and necessity for NBS for the use of NBS does not necessarily translate to higher levels of adoption of DRR measures. Countries such as China and the U.S., as well as European countries do not cluster together. This can be explained by the fact that DRR measures can refer to policies and actions that do not involve natural capital use or operate independently of it. Our analysis instead highlights that both national capability and necessity for NBS (from the results of the cluster analysis in Table 6) need to be high to facilitate wider adoption of DRR measures through NBS. In other words, DRR measures cannot be tied to NBS adoption, instead NBS can facilitate risk climate change-related DRR but are not the only means to do so. For example, the UK, that has the higher DRR score of 1 from all countries is found in Group 1. The UK Government's Climate Change Committee has identified 31 priority recommendations to reduce climate change risk, with only 8 of them referring explicitly to NBS such as peatland restoration and adoption of Sustainable Urban Drainage Systems (SuDS) (Adaptation Sub-Committee, 2015).

5.1. Recommendations for policy and conceptual frameworks

The empirical literature has highlighted some drivers of NBS potential have not been included in this work. As the approach of this paper was data-driven (at the global level), indicators used were of a 'coarse' nature and did not always reveal the complexity that is associated with conceptualising and implementing disaster-reducing NBS at the country level. The spatial and information extent of indicators used also was coarse, as city-level data should be more informative regarding drivers for NBS (Kabisch et al., 2016). Land under agricultural practices, for example, can be and indicator of necessity as proper management can reduce CO2 emissions (Girardin et al., 2021) and presence of rivers and their structure in a country (Chausson et al., 2020) can act as an indicator of capability but such data tend to exist at the local level (Coles and Tyllianakis, 2019) and cannot always be upscaled at the country level. Taking into account other elements of natural capital such as coral reef and mangrove cover should also be used to explain capability, as such ecosystems are found to mitigate the economic impacts of climate change in countries with high concentrations of population in urban areas by the coastline (Beck et al., 2018; (Kalantari et al., 2018)). Other potential indicators can refer to measures such as political stability in a country (to ensure that announced policy reforms will be put into action in the future), the public's acceptance of NBS as agents of risk reduction (Anderson and Renaud, 2021). Finally, indicator use is constrained as only the current state of the natural environment within countries is taken into account and not that of the future.

A need for an analysis framework is exacerbated by the amount of investments made in the area of NBS development. Investment in research, innovation and applications in NBS has currently been spearheaded by the European Commission (total funding for the environment-supporting FP7 programmes in the period 2007–2013 was €50 billion, European Commission, 2007). In terms of NBS-specific projects funded, the records of the European Investment Bank projects report investments of €39.5 million in country-wide and city-wide projects to support and enhance the environment and combat climate change. Also, the European Commission has recently pledged that 25 % of future EU budgets will be devoted to NBS and that it will provide incentives and lift barriers for businesses to invest in NBS (European Commission, 2020). By 2020, the European Commission had earmarked 240 million Euros for specifically NBS-related projects (Cohen-Shacham et al., 2019). Additionally, the Commission is planning for at least €10 billion over the next 10 years to become available for NBS through public/private blended finance. Despite such financing efforts, the global mitigation benefits offered from NBS is disproportionate to the funding they currently receive. NBS are measured to offer around 37 % of all potential CO_2 mitigation between the present and 2030 (Griscom et al., 2017) but receive only 0.8 % of the total available funds in public and private climate financing (Buchner et al., 2015). Private investments in NBS are on the rise, with an increasing rate in the last five years (Buchner et al., 2019) which should encourage an even higher increase in similar funding in the future, especially in NBS-related sectors where private investment has always been critical such as water sanitation and provisioning sectors, along with climate resilience. Finally, what is also required is the development of NBS-related markets where information, good practices and innovation opportunities support NBS implementation in the city and regional level (Faivre et al., 2017).

Introducing NBS in policy-making decisions has already been initiated from large entities such as the EU and China. Nevertheless, what appears to still be lacking is the translation of intentions in high-policy level into city or community-wide initiatives and actions. For example, NBS have been found to be more likely to be implemented in a successful manner when communities and people embrace the concept of NBS and actively support its implementation (Gulsrud et al., 2018). In order for a true increase in a country level of adoption for NBS a real paradigm shift needs to take place were communities and decision-makers alike embrace and continuously support NBS implementation over time. Acknowledging that, the European Commission now claims that, since public authorities represent 14 % of the EU's GDP, they will be the drivers for increased demand in NBS (European Commission, 2020). Whether this will be matched by the public's acceptance of NBS is more context and information dependant (Raymond et al., 2016; Young et al., 2019). Other barriers to increased demand for NBS implementation can be, apart from the lack of natural resources, institutional and political obstacles. In the long run, as NBS generally have longer implementation periods than traditional infrastructure as natural ecosystems take longer to grow or recover (Monty et al., 2017). More importantly, what is needed is a paradigm shift where NBS are viewed as vehicles of humans working with nature (Bark et al., 2021) instead of nature being simply the fuel of economic growth in an "extract, use, discard" scenario (Pearce and Turner, 1990).

6. Conclusions

NBS have been increasingly presented as means to protect and enhance natural resources while working alongside them to support livelihoods and reduce disaster risk. The aim of this work is to make a contribution to the global NBS discussion on how their potential for mainstreaming could be assessed, and provide outputs based on existing available data which could (and should) be updated as new and better data become available. This work aims to present a suggested typology for indicators allowing to inform policy discussions for resource allocation for disaster-reducing NBS. We conceptualised capability indicators that reflect the existence of mechanisms to enable the adoption of NBS as adaptation and mitigation actions to prevent harm from the threats defined by climate change, while indicators of necessity were selected to reflect exposure to specific threats, or the vulnerability of a country to these threats, where NBS are perceived as offering significant protection against harm.

The quantitative analysis illustrated that countries that score higher in both national capability and necessity indicators are clustered together, a result not affected by geographical or economic characteristics. Such countries represent a mixture of large economies, small European and Balkan countries as well as coastal and island nations from across the world and appear to have already started to adopt measures to reduce climate change-related risk. Included in these countries are pioneers of advocating for Ecosystem-based Adaptation and Nature-based Solutions as means of reducing climate change risk, as well as countries that have not been known for incorporating NBS in achieving DRR. Our results show that, higher capability and necessity for NBS might also explain current adoption of national measures of achieving DRR, showing potential synergies between DRR-reducing NBS and grey infrastructure projects. Finally, our work highlights the need for better data availability to allow for more detailed and appropriate indicators of capability and necessity for disaster-reducing NBS.

CRediT authorship contribution statement

Emmanouil Tyllianakis: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft. **Julia Martin-Ortega**: Conceptualization, Writing – review & editing**. Steven A Banwart**: Conceptualization, Writing – review & editing, Supervision, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This paper has received funding from the European Union's Horizon 2020 research and innovation programme, Call H2020-SC5-2016-2017 Greening the economy, under grant agreement No 730338.

Appendix

See Tables A1 and B1 in appendix section.

References

Abdul-Wahab, S.A., Bakheit, C.S., Al-Alawi, S.M., 2005. Principal component and multiple regression analysis in modelling of ground-level ozone and factors affecting its concentrations. Environ. Model. Softw. 20 (10), 1263–1271.

Adaptation Sub-Committee, 2015. Progress in preparing for climate change: 2015 Report to Parliament. London: Committee on Climate Change, 6, p.E3S. Available at: ⟨https://www.theccc.org.uk/wp-content/uploads/2015/06/6.736_CCC_ASC_Adaptation-Progress-Report_2015_FINAL_WEB_070715_RFS.pdf⟩ (last accessed 2/09/2021).

Albert, C., Spangenberg, J.H., Schröter, B., 2017. Nature-based solutions: criteria. Nature 543 (7645), 315-315.

de Almeida, L.Q., Welle, T., Birkmann, J., 2016. Disaster risk indicators in Brazil: a proposal based on the world risk index. Int. J. Disaster Risk Reduct. 17, 251–272.

Anderson, C.C., Renaud, F.G., 2021. A review of public acceptance of nature-based solutions: the 'why','when', and 'how'of success for disaster risk reduction measures. Ambio 1–22.

Arnbjerg-Nielsen, K., Willems, P., Olsson, J., Beecham, S., Pathirana, A., Bülow Gregersen, I., Madsen, H., Nguyen, V.T.V., 2013. Impacts of climate change on rainfall extremes and urban drainage systems: a review. Water Sci. Technol. 68 (1), 16–28.

Bark, R.H., Martin-Ortega, J., Waylen, K.A., 2021. Stakeholders' views on natural flood management: Implications for the nature-based solutions paradigm shift? Environ. Sci. Policy 115, 91–98.

Beck, M.W., Losada, I.J., Menéndez, P., Reguero, B.G., Díaz-Simal, P., Fernández, F., 2018. The global flood protection savings provided by coral reefs. Nat. Commun. 9 (1), 1–9.

Birkmann, J., von Teichman, K., 2010. Integrating disaster risk reduction and climate change adaptation: key challenges—scales, knowledge, and norms. Sustain. Sci. 5 (2), 171–184.

Buchner, B., Clark, A., Falconer, A., Macquarie, R., Meattle, C., & Wetherbee, C. (2019). Global landscape of climate finance 2019. Available at: https://www.climatepolicyinitiative.org/wp-content/uploads/2019/11/2019-Global-Landscape-of-Climate-Finance.pdf.

Society of Ecological Restoration (SER) International Science, Policy Working Group, 2004. The SER International Primer on Ecological Restoration. Society for Ecological Restoration International, Tucson, AZ.

van den Bosch, M., Sang, Å.O., 2017. Urban natural environments as nature-based solutions for improved public health–a systematic review of reviews. Environ. Res. 158, 373–384.

Brander, L.M., Van Beukering, P., Nijsten, L., McVittie, A., Baulcomb, C., Eppink, F.V., van der Lelij, J.A.C., 2020. The global costs and benefits of expanding marine protected areas. Mar. Policy 116, 103953.

Brock, G., Pihur, V., Datta, S., Datta, S., 2011. clValid, an R package for cluster validation. Journal of Statistical Software (Brock et al., March 2008).

Buchner, B., Trabacchi, C., Mazza, F., Abramskiehn, D., Wang, D., 2015. Global Landscape of Climate Finance 2015: A Climate Policy Initiative Report. ⟨www.climatepolicyinitiative.org⟩.

Calliari, E., Staccione, A., Mysiak, J., 2019. An assessment framework for climate-proof nature-based solutions. Sci. Total Environ. 656, 691–700.

Castellar, J.A.C., Popartan, L.A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Acuna, V., 2021. Nature-based solutions in the urban context: terminology, classification and scoring for urban challenges and ecosystem services. Sci. Total Environ. 779, 146237.

Chang, S.E., Yip, J.Z., Conger, T., Oulahen, G., Marteleira, M., 2018. Community vulnerability to coastal hazards: developing a typology for disaster risk reduction. Appl. Geogr. 91, 81–88.

Chausson, A., Turner, B., Seddon, D., Chabaneix, N., Girardin, C.A., Kapos, V., Seddon, N., 2020. Mapping the effectiveness of nature-based solutions for climate change adaptation. Glob. Change Biol. 26 (11), 6134–6155.

Chen, Q., Mei, K., Dahlgren, R.A., Wang, T., Gong, J., Zhang, M., 2016. Impacts of land use and population density on seasonal surface water quality using a modified geographically weighted regression. Sci. Total Environ. 572, 450–466.

Cohen-Shacham, E., Walters, G., Janzen, C., Maginnis, S., 2016. Nature-based solutions to address global societal challenges. IUCN: gland. Switzerland 97.

Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M., Kumar, C., Walters, G., 2019. Core principles for successfully implementing and upscaling Nature-based Solutions. Environ. Sci. Policy 98, 20–29.

Coles, N.A.and Tyllianakis, E. (2019). Coordination and support actions. NBS Market Potential Through Synergies at International Level: Business Plan Case Studies and Scope for International Mainstreaming. Deliverable D7.3 of the Horizon 2020 Project ThinkNature: Development of a Multi-stakeholder Dialogue Platform and Think Tank to Promote Innovation With Nature Based Solutions. Available at: ⟨https://platform.think-nature.eu/system/files/project_deliverable/deliverable_7.3_.pdf⟩.

Connop, S., Vandergert, P., Eisenberg, B., Collier, M.J., Nash, C., Clough, J., Newport, D., 2016. Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. Environ. Sci. Policy 62, 99–111.

Cuny, H.E., Rathgeber, C.B., Frank, D., Fonti, P., Mäkinen, H., Prislan, P., Fournier, M., 2015. Woody biomass production lags stem-girth increase by over one month in coniferous forests. Nat. Plants 1 (11), 1–6.

Davidson, D.J., Williamson, T., Parkins, J.R., 2003. Understanding climate change risk and vulnerability in northern forest-based communities. Can. J. For. Res. 33 (11), 2252–2261.

DG Environment (2015). Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities' ISBN 978–92-79–46051-7. doi:⟨10.2777/765301⟩.

Ding, C., He, X., 2004. July. K-means clustering via principal component analysis. Proc. Twenty-first Int. Conf. Mach. Learn. 29.

Duckett, D., Feliciano, D., Martin-Ortega, J., Munoz-Rojas, J., 2016. Tackling wicked environmental problems: the discourse and its influence on praxis in Scotland. Landsc. Urban Plan. 154, 44–56.

Dudley, N., Stolton, S., Belokurov, A., Krueger, L., Lopoukhine, N., MacKinnon, K., Sandwith, T., Sekhran, N., 2010. Natural solutions: protected areas helping people cope with climate change.

Eckstein, D., Künzel, V., & Schäfer, L., 2017. Global climate risk index 2018. Germanwatch, Bonn. ⟨https://germanwatch.org/de/14638⟩.

Eggermont, H., Balian, E., Azevedo, J.M.N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., 2015. Nature-based solutions: new influence for environmental management and research in Europe. GAIA-Ecol. Perspect. Sci. Soc. 24 (4), 243–248.

Escobedo, F.J., Giannico, V., Jim, C.Y., Sanesi, G., Lafortezza, R., 2019. Urban forests, ecosystem services, green infrastructure and nature-based solutions: Nexus or evolving metaphors? Urban For. Urban Green. 37, 3–12.

European Commission, 2007. FP7 in Brief. ⟨https://ec.europa.eu/research/fp7/pdf/fp7-inbrief_en.pdf⟩.

European Commission (2013). An EU Strategy on adaptation to climate change. COM (2013) 216 final.

European Commission (2017). Action Plan for nature, people and the economy. Available at: ⟨https://ec.europa.eu/environment/nature/legislation/fitness_check/action_plan/index_en.htm⟩.

European Commission (2018) Nature-Based Solutions. Available at: ⟨https://ec.europa.eu/research/environment/index.cfm?pg=nbs⟩.

European Commission (2020). EU Biodiversity Strategy for 2030 Bringing nature back into our lives. Available at: ⟨https://ec.europa.eu/info/sites/info/files/communication-annex-eu-biodiversity-strategy-2030_en.pdf⟩.

Faivre, N., Fritz, M., Freitas, T., de Boissezon, B., Vandewoestijne, S., 2017. Nature-Based Solutions in the EU: innovating with nature to address social, economic and environmental challenges. Environ. Res. 159, 509–518.

Faivre, N., Sgobbi, A., Happaerts, S., Raynal, J., Schmidt, L., 2018. Translating the Sendai Framework into action: the EU approach to ecosystem-based disaster risk reduction. Int. J. Disaster Risk Reduct. 32, 4–10.

Frantzeskaki, N., Vandergert, P., Connop, S., Schipper, K., Zwierzchowska, I., Collier, M., Lodder, M., 2020. Examining the policy needs for implementing nature-based solutions in cities: Findings from city-wide transdisciplinary experiences in Glasgow (UK), Genk (Belgium) and Poznań (Poland). Land Use Policy 96, 104688.

Gaillard, J.C., Mercer, J., 2013. From knowledge to action: bridging gaps in disaster risk reduction. Prog. Hum. Geogr. 37 (1), 93–114.

Girardin, C.A., Jenkins, S., Seddon, N., Allen, M., Lewis, S.L., Wheeler, C.E., Malhi, Y., 2021. Nature-based solutions can help cool the planet—if we act now, 2021 Nature (593), 191–194. https://doi.org/10.1038/d41586-021-01241-2.

Gough, I., 2001. Social assistance regimes: a cluster analysis. J. Eur. Soc. Policy 11 (2), 165–170.

Griscom, B.W., Adams, J., Ellis, P.W., Houghton, R.A., Lomax, G., Miteva, D.A., Schlesinger, W.H., Shoch, D., Siikamäki, J.V., Smith, P., Woodbury, P., 2017. Natural climate solutions. Proc. Natl. Acad. Sci. 114 (44), 11645–11650.

Gulsrud, N.M., Hertzog, K., Shears, I., 2018. Innovative urban forestry governance in Melbourne?: Investigating "green placemaking" as a. Nat. -Based Solut. Environ. Res. 161, 158–167.

Hiwasaki, L., Luna, E., Shaw, R., 2014. Process for integrating local and indigenous knowledge with science for hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities. Int. J. Disaster Risk Reduct. 10, 15–27.

HM Government (2021). Net Zero Strategy: Build Back Greener. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1033990/net-zero-strategy-beis.pdf(last accessed July 2022).

Intergovernmental Panel on Climate Change (IPCC), 2018. Global Warming of 1.5° C: An IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Available at: ⟨www.ipcc.ch/sr15/⟩.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., Bonn, A., 2016. Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. Ecol. Soc. 21 (2).

Kalantari, Z., Ferreira, C.S.S., Keesstra, S., Destouni, G., 2018. Nature-based solutions for flood-drought risk mitigation in vulnerable urbanizing parts of East-Africa. Curr. Opin. Environ. Sci. Health 5, 73–78.

Karmakar, B., Das, S., Bhattacharya, S., Sarkar, R., Mukhopadhyay, I., 2019. Tight clustering for large datasets with an application to gene expression data. Sci. Rep. 9 (1), 1–12.

Lattin, J.M., Carroll, J.D. and Green, P.E., 2003. Analyzing multivariate data (pp. 351–352). Pacific Grove, CA: Thomson Brooks/Cole.

Lechner, A.M., McCaffrey, N., McKenna, P., Venables, W.N., Hunter, J.T., 2016. Ecoregionalization classification of wetlands based on a cluster analysis of environmental data. Appl. Veg. Sci. 19 (4), 724–735.

Leisher, C., 2015. How useful to biodiversity conservation are ecosystem services-based approaches? Water ecosystem services, a global perspective. Cambridge University Press,, Cambridge, UK, pp. 65–70.

Maes, J., Jacobs, S., 2017. Nature-based solutions for Europe's sustainable development. Conserv. Lett. 10 (1), 121–124.

McGranahan, G., Balk, D., Anderson, B., 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environ. Urban. 19 (1), 17–37.

McMichael, C., Dasgupta, S., Ayeb-Karlsson, S., Kelman, I., 2020. A review of estimating population exposure to sea-level rise and the relevance for migration. Environ. Res. Lett. 15 (12), 123005.

Mercer, J., Kelman, I., Taranis, L., Suchet-Pearson, S., 2010. Framework for integrating indigenous and scientific knowledge for disaster risk reduction. Disasters 34 (1), 214–239.

Mitchell, R.J., Richardson, E.A., Shortt, N.K., Pearce, J.R., 2015. Neighborhood environments and socioeconomic inequalities in mental well-being. Am. J. Prev. Med. 49 (1), 80–84.

Monty, F., Murti, R., Miththapala, S., Buyck, C. (2017). Ecosystems protecting infrastructure and communities: lessons learned and guidelines for implementation. IUCN, Gland.

Mori, A.S., Dee, L.E., Gonzalez, A., Ohashi, H., Cowles, J., Wright, A.J., Isbell, F., 2021. Biodiversity–productivity relationships are key to nature-based climate solutions. Nat. Clim. Change 11 (6), 543–550.

Mortimore, M., 2010. Adapting to drought in the Sahel: lessons for climate change. Wiley Interdiscip. Rev. Clim. Change 1 (1), 134–143.

Narayan, S., Beck, M.W., Reguero, B.G., Losada, I.J., Van Wesenbeeck, B., Pontee, N., Burks-Copes, K.A., 2016. The effectiveness, costs and coastal protection benefits of natural and nature-based defences. PloS One 11 (5), e0154735.

Pearce, D.W. and Turner, R.K., 1990. Economics of natural resources and the environment. JHU press.

Odum, H.T., Odum, B., 2003. Concepts and methods of ecological engineering. Ecological Engineering 20 (5), 339–361.

Oppla (2021). EU Repository of Nature-Based Solutions. Available at: https://oppla.eu/case-study-finder.

Popp, A., Humpenöder, F., Weindl, I., Bodirsky, B.L., Bonsch, M., Lotze-Campen, H., Dietrich, J.P., 2014. Land-use protection for climate change mitigation. Nat. Clim. Change 4 (12), 1095–1098.

Raymond, C.M., Gottwald, S., Kuoppa, J., Kyttae, M., 2016. Integrating multiple elements of environmental justice into urban blue space planning using public participation geographic information systems. Landsc. Urban Plan. 153, 198–208.

Schipper, E.L.F., Thomalla, F., Vulturius, G., Davis, M., Johnson, K., 2016. Linking disaster risk reduction, climate change and development. International Journal of Disaster Resilience in the Built Environment.

Schipper, L., Pelling, M., 2006. Disaster risk, climate change and international development: scope for, and challenges to, integration. Disasters 30 (1), 19–38.

Seddon, N., Sengupta, S., García-Espinosa, M., Hauler, I., Herr, D., Rizvi, A.R. (2019). Nature-based Solutions in Nationally Determined Contributions: Synthesis and recommendations for enhancing climate ambition and action by 2020. Gland, Switzerland and Oxford, UK: IUCN and University of Oxford.

Short, C., Clarke, L., Carnelli, F., Uttley, C., Smith, B., 2019. Capturing the multiple benefits associated with nature-based solutions: lessons from a natural flood management project in the Cotswolds, UK. Land Degrad. Dev. 30 (3), 241–252.

de Sousa Mendes, G.H., Miller Devós Ganga, G., 2013. Predicting success in product development: the application of principal component analysis to categorical data and binomial logistic regression. J. Technol. Manag. Innov. 8 (3), 83–97.

Stern, N.and Stern, N.H. (2007). The economics of climate change: the Stern review. Cambridge University press.

The Royal Society (2014). Resilience to extreme weather. The Royal Society Science Policy Centre report 02/14. Issued: November 2014 DES3400, ISBN: 978–1-78252–113-6.

UNEP (2019). Contribution to Track #6 Nature-Based Solutions by the EU/European Commission drawing on existing policies and strategies. Available online at: ⟨http://wedocs.unep.org/bitstream/handle/20.500.11822/29767/joining_forces.pdf?sequence=1&isAllowed=y⟩.

United Nations, 2015. Transforming our World: The 2030 Agenda for Sustainable Development available at: ⟨https://sustainabledevelopment.un.org/post2015/transformingourworld/publication⟩ (last accessed 20/20/2021).

Willemen, L., Scheldeman, X., Cabellos, V.S., Salazar, S.R., Guarino, L., 2007. Spatial patterns of diversity and genetic erosion of traditional cassava (Manihot esculenta Crantz) in the Peruvian Amazon: An evaluation of socio-economic and environmental indicators. Genet. Resour. Crop Evol. 54 (7), 1599–1612.

Young, A.F., Marengo, J.A., Coelho, J.O.M., Scofield, G.B., de Oliveira Silva, C.C., Prieto, C.C., 2019. The role of nature-based solutions in disaster risk reduction: the decision maker's perspectives on urban resilience in São Paulo state. Int. J. Disaster Risk Reduct. 39, 101219.

Zingraff-Hamed, A., Schröter, B., Schaub, S., Lepenies, R., Stein, U., Hüesker, F., Meyer, C., Schleyer, C., Schmeier, S., Pusch, M.T., 2020. Perception of bottlenecks in the implementation of the European Water Framework Directive. Water Altern. 13 (3), 458–483.

Zingraff-Hamed, A., Hüesker, F., Albert, C., Brillinger, M., Huang, J., Lupp, G., Schröter, B., 2021. Governance models for nature-based solutions: seventeen cases from Germany. Ambio 50 (8), 1610–1627.