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Natural Assurance Scheme: a level playing field framework for Green-Gray infrastructure development

1. Introduction:

Global warming is projected to intensify the hydrological cycle and increase the occurrence and frequency of flood events as well as water scarcity and droughts in large parts of Europe and other regions around the world. The Economics of Climate Change working group estimated annual damages to GDP due to climate risk to rise by 77% by 2030 (IPCC, 2014). Meanwhile, first global assessments of the services provided by freshwater ecosystems (watersheds, aquifers, and wetlands) for flood control, irrigation, industry, recreation, waterway transportation, and others, estimates their value reaching several trillion dollars annually. Climate change is an additional stress factor for ecosystems, putting their structure and functioning at risk and undermining their resilience to other pressures (Martin et al., 2012). This continued degradation and erosion of natural capital greatly amplifies these risks. Maes et al. showed that large investments to increase the volume and use of green infrastructure just to maintain the current level of ecosystem services under present trends of land use change (Maes et al., 2014). However, it is unlikely that scaling existing measures will be enough as the dynamics of natural systems are highly complex and some impacts of environmental change is irreversible and the replacement of natural capital is often impossible, or the investment and process to replace can carry significant risks of its own (European Environment Agency, 2015). This inherit complexity of ecosystems also leads to challenges in translating the concept of natural resilience into policy and its uptake into Disaster risk reduction (DRR) planning. This leads to relatively low levels of risk awareness on the possible impacts of losses of natural capital and the potential of Nature Based Solution (NBS) to mitigate them. NBS are solutions to societal challenges that are inspired and supported by nature (Raymond et al., 2017). This constitute a different research paradigm because research project are mainly designed to test value without taking in account industry's requirement for effective upscaling in real life conditions.

This works aims to enable NBS to be piloted in a more “bankable format” so that commercial finance can be blended with public or concessional finance, or at least into “procurable projects” that can be contracted under performance-based regimes. To do so, it presents a stepwise Framework to embody the valuation of the Insurance value function of healthy Ecosystems Value in concrete project cases called Natural Assurance Schemes (NAS). The common research and industry reference thereby created aims to initiate a focus on operationalization through action research. It focuses on the inception of processes to be replicated, tested and improved continuously to build up a consistent track record and proof of concept of different types of NBS. This envisions to accelerate NBS intake through demonstration of their compatibility with existing infrastructure processes and newly possible comparisons. As such, the presented Framework is of a conceptual nature, which application would provide the empirical evidence to further refine it.

As Risk Reduction perspective offers a vision of preventive safeguards (whether physical or societal), the authors argue that in the context of the presented increased uncertainty about future environmental catastrophes onsets and intensity, there is a need to shift to a Disaster Resilience Enhancement (DRE) paradigm[1], placing practical decision-making and implementation in Disaster Management within the shift from Risk to Resilience Management described by (Linkov et al., 2014). This DRE answers the need identified by Park et al (2013) to include unexpected perturbation over classical risk reduction performed in engineered

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[1] We use the IPCC definition of Resilience as “the capacity of social, economic, and environmental systems to cope with a hazardous event, responding or reorganizing in ways that maintain their essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation” (IPCC, 2014).

systems (Park et al., 2013). In other words to go from the assumption that we can prevent and eliminate all risk to a paradigm where we are aware that is impossible, and therefore try to find the optimum between prevention and “preparedness”.

Enhancing resilience of the natural capital will require the integration of a combination of structural (infrastructure resilience) and non-structural measures (social resilience). Such measures can be cost-effective and instrumental to save lives, prevent and reduce losses (risk reduction, but most importantly, ensure effective recovery and rehabilitation (enhance resilience). In this context, the Nature Based Solutions (NBS) will play an integral role in enhancing disaster resilience by exploiting the multi-functionality of intrinsically resilient natural processes.

After defining NAS, existing knowledge gaps and obstacles for the incorporation of the insurance value potential produced by an NBS into planning, investment and decision making are reviewed. This looks at three primary areas: the present and potential place of (re)insurance industry; the ecological and physical uncertainty; and resilience modelling challenges. This is followed by an analysis of institutional structures related to infrastructure, social integration and finance and the possible barriers faced in ‘operationalizing’ an NAS. This is followed by the introduction of the NAS operationalization framework which proposes a process and potential steps to address the identified anticipated challenges.

2. Background

2.1 The Principle of NAS operational Methodology

Risk is commonly defined by the combination of hazard potential, exposure and vulnerability. NBS can contribute by optimizing the delivery from and resilience of ecosystems that can provide these services to reduce vulnerability to disaster. Hence, an important opportunity lies in the potential to capitalize on the services provided by fully functioning ecosystems as a “natural” assurance system composed of “green infrastructure”. Natural assurance schemes (NAS) are NBS based strategies to internalize the insurance value of ecosystems. This is applied as a conceptual handle to improved awareness, valuation and service focused planning. Insurance value is defined as reflecting an ecosystem’s capacity to remain in a given regime and retain its capacity to deliver vital ecosystem services in the face of disturbance and change (Baumgärtner, 2007). In Figure 1 we present the interaction framework that we consider between Insurance value of an ecosystem and resilience. NAS is then a solution to mainstream the use of natural water retention measures (NWRMs) into DRE, by focusing on their insurance value and therefore including ecosystems into infrastructure thinking.

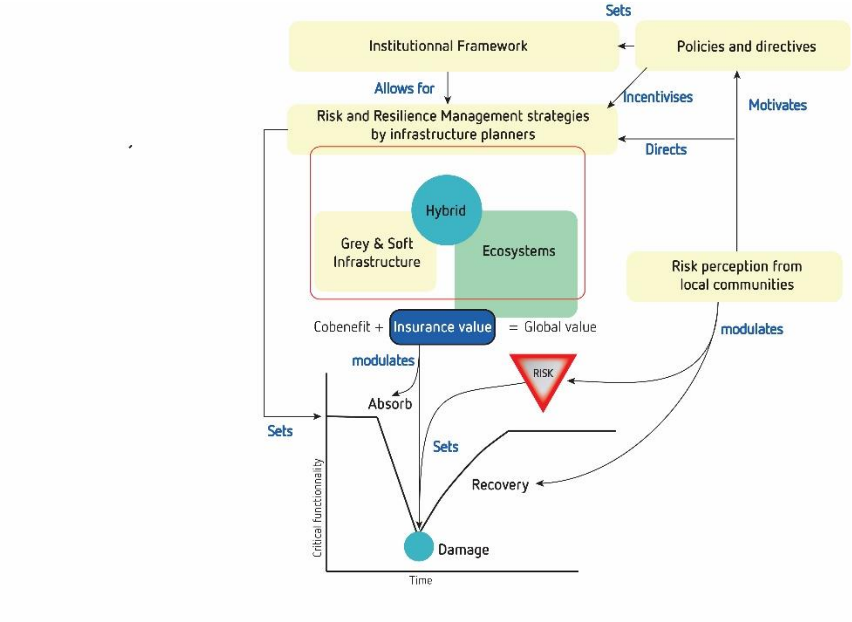

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Figure 1: Insurance Value within a resilience framework. Conceptually, the insurance value modulates both the absorption of a perturbation and extent of the loss in Critical functionality within the resilience framework as proposed by Linkov et al. 2014 contributing to the dynamic interplay of risk and resilience. Here critical functionality is considered as a process which, if interrupted will jeopardize the continued existence of the system. Risk perception includes both local stakeholders whose readiness shall directly impact the damage and recovery functions, but also to on the upper part perception from policy makers themselves on the risk under their jurisdiction.

One of the key potentials of NAS to support disaster resilience enhancement is the fact that hazards and potential economic losses are turned into an opportunity to transform the whole system, finding new incentives and potential economic instruments and financing schemes. Therefore it lays the grounds for policy adjustments and enhanced coordination between different policy areas which are seen as a pre-requisite for enhancing the chances of the multiple benefits of NWRMs to be considered appropriately in management decisions.

Here we present a practical NAS development framework that includes the physical, socio-cultural and valuation aspects adapted to the institutional frame to align economic incentives and financial flows. A convenient analogy is the comparison to services delivered by traditional grey infrastructure.

NAS schemes build on the ecosystems capacity to self-recover and to exhibit long term outperformance (Figure 2) to designed optimal mixed Green-Grey solutions. Non-the less, recognition of Cultural capital to be intrinsic to natural capital as put forward in the Charter of Rome on Natural and Cultural Capital is an important aspect in support of NBS as contribution to societal wellbeing[2].

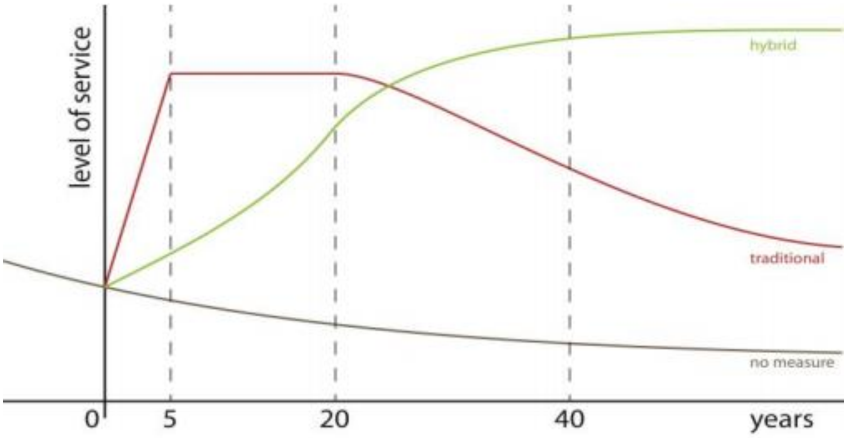

Figure 2: Grey vs Green Infrastructure qualitative natural capital dynamics. From Altamirano et al. (2013)

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[2] https://circabc.europa.eu/webdav/CircaBC/env/biodiversity_nature/Library/CGBN%20-%2017th%20meeting%20-%2025%20%26%2026%20September%202014/Documents/Agenda%20item%204.2.%20Charter_of_Rome_August2014.pdf

2.2 Defining the NBS innovation

Traditionally, green infrastructure or NBS, have been designed through conservation of natural areas, through legal protection of natural reserves and backed funded up directly by government subsidies. There has been also many different programs and subsidies within the CAP (Common Agricultural Policy) such as the agro-environmental subsidies, that had in mind making payments for environmental services with the aim of increasing environmental infrastructure for the good of society and nature. But since already more than a decade, scientists have alerted of the low cost-effectiveness of conservation payment and the comparatively high potential of ecosystem service thinking (Ferraro and Simpson, 2002). While this helped the emergence of ecosystem services concept , both the possible adverse effect of market based mechanisms (Landell-Mills and Porras, 2002) and lack of proper framework have limited its development outside of limited legal frameworks. In this work the authors do not rally to the “New Conservation Science” (NCS) as defined by Doak et al. as we acknowledge the incapacity of anthropocentric methods to fully protect biodiversity (Doak et al., 2014). Nevertheless NAS are presented as an additional mechanism to value and support assurance services that are unaccounted for and can potentially channel additional funding towards required conservation actions.

Green infrastructure can turn into a cost-effective, resilient approach to managing climatic impacts. The river restoration community, experiencing major expansion in the last decades, was one of the first to realize and act on the fact that the natural structure of rivers and streams greatly attenuates the risks humanity faces due to climate change and other anthropogenic impacts. By now, the multiple benefits NWRMs can deliver and their capacity to contribute simultaneously to the achievement of the objectives of different European Union (EU) policies are well recognized (RESTORE, REURIS, (Strosser et al., 2015)). In view of the predicted climate change, Burek et al. (2012) have shown that no-regret NWRMs can locally contribute to increased low flows, reduced flood peaks, improved groundwater recharge and decreased water stress up to 20 % in Europe (Burek et al., 2012). Numerous case studies have demonstrated cost effective NBS for disaster risk reduction (Bresch, 2016).

2.3 Challenges in risk assessment and disaster resilience enhancement

2.3.1 Insurance and (re-)insurance

The insurance industry will have an increasingly important role in helping society to adapt and become more resilient to disaster. Beyond its core function to provide risk coverage, insurance assists with risk identification and data collection, assessment and modeling and does provide economic incentives to better manage risks, e.g. to invest in risk prevention and to strengthen risk resilience, as this can lower the price of insurance (Crichton, 2008). Insurance allows for an ex-ante or pre-financing approach to provide funds to cover the damage caused by a disaster to assets and livelihoods that result from catastrophic events. This accelerates the process of economic recovery from the event. Insurance does not usually provide the funds required for the implementation of risk reduction measures. This is mainly due to the fact that insurance is most often underwritten on an annual basis and due to market forces, the return on investment cannot be guaranteed. For example, a policy holder might contract with an insurance provider in year one to reap the benefits of co-financing prevention and then switch to another insurance provider in year two, which offers a lower premium rate as a result of that prevention being in place as they do not need to recover the initial costs of the risk reducing investment. Nevertheless, insurance can contribute to climate resilience by strengthening the financial (and therefore material) resilience of insured entities, as well as by incentivizing investment in DRE measures, including adaptation (Warner et al., 2012)

As demonstrated by Baumgärtner and Strunz (2014), the damage-reducing value of ecosystems (and hence reduction in the price for insurance, i.e. the premium) alone may be too limited to act as an sole incentive to their preservation in many cases (Baumgärtner, 2007) – but once co-benefits (such as hatchery of fish in the case of mangroves) are considered, the case may become stronger. Nevertheless, the expertise of the insurance industry is crucial as it possesses the state of the art capacity in risk assessment and can be an enabler of best practice in risk management. This central position is particularly highlighted by the database of past disaster which is crucial for model calibration. Data of the French Caisse Centrale de Réassurance (CCR[3]) for example represents up to 90% of the market share for risks and more than 60% for losses. Similar datasets at the global level have been collected by both MunichRe and Swiss Re[4] . Although these data cannot be shared for reasons of confidentiality, insurers and reinsurers use them to develop models for estimating the impacts of natural disaster (eg. Moncoulon et al. 2014). Beyond their insurance activities, these tools can then be used as part of public-private partnerships for exposure studies and cost-benefit analysis, as a service. As reported by the Geneva association, Insurance and reinsurance companies have already acknowledged NBS place in climate change adaptation and their contribution to the UN creation of the A2R (anticipate, absorb and reshape) initiative (McGavick, 2016). Regarding the core issue of risk assessment (i.e. the 'anticipate' in A2R), two recent developments warrant mention (See Box1), namely climada, the open-source Economics of Climate Adaptation modelling platform (Bresch, 2014) and the Oasis loss modeling framework which can handle an integration of NBS as adaptation measures and the evaluation of their effect on risk.

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[3] https://www.ccr.fr, mandated by the state, provides insurers operating in France with coverage of exceptional risks.

[4] https://www.munichre.com/en/reinsurance/business/non-life/natcatservice/annual-statistics/index.html; www.swissre.com/sigma

Oasis loss modeling framework (LMF) [1]

Oasis LMF[1] is an open architecture platform to foster throughout the wide community of those interested in modelling catastrophic risk across business, academia and government. Oasis LMF is an open access, plug and play, calculation kernel that calculates damage and financial risk from catastrophic events now supported by 44 major insurers and reinsurers and a spin-out company Oasis Palm Tree Ltd, providing education and services around the Oasis system. Oasis models will publish their modelling assumptions such that they can be used more transparently to assist model use for planning purposes and to underwriting risks. Oasis LMF is intended to cause a market disruption of the current ‘black box’, prohibitively expensive CAT modelling market, bringing more open and transparent models to the market.

climada - the open-source Economics of Climate Adaptation (ECA) platform[2]

climada[1] stands for climate adaptation, the open source natural catastrophe model that implements the Economics of Climate Adaptation (ECA) methodology. It is an open source probabilistic natural catastrophe damage model, but it also quantifies averted damages (benefits) thanks to adaptation measures of any kind (varying from structural measures grey to green infrastructure, up to behavioral, etc.). It is based on four elements, namely: Hazard, Exposure, Vulnerability (c.f. damage functions) and Adaptation measures.
While the first three elements constitute risk (risk = hazard x exposure x vulnerability), the fourth element allows for the quantification of risk mitigating measures. A Cost/benefit perspective is provided by specific measure’s costs set by the user. This is not restricted to monetary terms, metrics like people affected can be used, too. climada is widely used, basis for several peer-reviewed publications (Bresch, 2016), and past and on-going collaborations show an already fruitful research-industry-civil society exchange on loss and damage modelling.

While climada implements the whole process from risk assessment to adaptation options appraisal, the Oasis LMF does focus on the risk assessment part, but offers a platform for parties to share their model components, either for free or under commercial terms. The climada model is capable of invoking the Oasis LMF kernel (ktools) and hence allows for full integration.

[1] http://www.oasislmf.org
[2] https://github.com/davidnbresch/climada

Box 1: Example of insurance industry model and platform to tackle Risk and Adaptation challenges

2.3.2 Modelling the potential of NAS: approaches and scope

Modelling the potential of NAS through simulating the effect of ecosystems and nature based solutions at various spatial scales (Janssen et al., 2015) is necessary to better understand the governing physical processes and its role in mitigating risks (Lavorela et al., 2017). This should be done alongside similar analysis for risk mitigation from grey infrastructure. The contribution of ecosystems to NAS can be considered at different scales, global, regional, and at the smaller catchment and urban scale. Models used for simulating the effect of ecosystems (NBS) to mitigate natural hazards like flooding are by definition simplified representations of the system they model which can be more or less complex (Refsgaard et al., 2012, 2006). In the context of DRR and CCA (van der Keur et al., 2016) this means that they are inherently uncertain. Spatial scale is a key issue to consider when modelling NBS. For example, to understand the role of green infrastructure in flood mitigation for urban areas it is necessary to understand the type of flooding that exercises the greatest risk for the built environment and infrastructure, like roads and the public transportation system. Flooding resulting from heavy rainfall excess, including cloudburst events or sustained rainfall over a long period of time, exceeding urban drainage capacity will require a very different approach to flooding that results from rainfall excess in the larger scale surrounding rural watershed which affects the hydrology of the city. Moreover, flood mitigation for some infrastructural developments, that take place within the floodplain of the river may not be addressable through NAS at all, especially for the most extreme floods in which case infrastructure should be moved or protected, e.g. by fortification of dikes, in the best way possible. The NAS of a landscape will depend upon its total storage capacity for water, which may comprise grey storage (behind dams), brown storage (soils, lakes) and green storage (vegetated lands and wetlands). Soil, canopy and wetland storage are addressable through nature conservation, agricultural practices and restoration measures. Assessing these sources is highly dependent upon remote sensing, which has become widely available and provides both large scale land cover data (e.g. Corine) and high resolution data (e.g. from the EU Copernicus programme). Earth observation data is therefore a valuable data source and is used for standalone ES mapping and also provides indispensable input to ES physical and socio-economic modelling (Ayanu et al., 2012) The effectiveness of this storage for flood mitigation will depend upon to the extent to which they already have absorbed water before a particular flood event (i.e. antecedent conditions) occurs. It is also impacted by where they occur in relation to the path between the rainfall event and the urban area that requires mitigation services. Modelling all of these at policy-relevant scales is challenging based on field data alone and must be supported by remote sensing and Geographical Information Systems (GIS). There are a number of global and regional analyses of flood risk (Pappenberger et al., 2012; Sampson et al., 2015; Ward et al., 2015). The WaterWorld tool[5] can model these factors for any geography and under current conditions as well as under different scenarios for change in land use and climate, which appears to be a practical innovation on current practice. As correlation between measures and resuling services can be assessed efficiently in a real-world situation if project level information is packaged properly in a single market place, this process can potentially allow for significantly improvement upon the predictive power of proposed actions, which currently is fairly weak (Lamouroux et al., 2015).

2.3.3 The resilience evaluation challenge

Robust and transferable ex-ante evaluation methods are required to convince both investors and public bodies of the potential reliability and economic relevance of NBS in the context of DRE. Since many cities do not incorporate the carrying capacity of the local ecosystems into their planning and development, there will be cases where reliance on highly engineered systems is the only option and NBS are not sufficient or even feasible. It must also be kept within the assessment the possibility that ecosystem would provide disservice within the present socio-economic framework (Pataki et al., 2011). Moreover, as static response curves (see Figures 2 to 5) start to be qualitatively accepted, dynamic responses to perturbations are much less trivial to produce and compare. One of the challenges is to identify the threshold that will set an ecosystem towards different adaptation strategies (e.g. desertification, species migration or new assemblage balance). Thresholds identification is crucial to set the limits of a safe operating space – even independently of the climatic events affecting an area. The

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[5] http://www.policysupport.org/waterworld

perception of the risks and their consequent management possibilities might set a basis for identifying initial limits. Some authors have argued that if precise thresholds cannot precisely be forested ex ante, early warning system like “critical slowing down” (Dakos et al., 2014) could be used to manage ecosystem transition.

The concept of ecosystem services is increasingly applied and integrated within the fields of ecology and water management. Terminology/definitions still need further conceptual refinement like e.g. differences/similarities to a natural capital framework. There is however a growing number of initiatives focused on developing standardized methodologies at global level (e.g. see Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)[6]), on how to standardize assessment methodology (MAES[7]), their potential valuation (InVALUABLE[8]), their operationalization (OPENNESS[9]) or the barriers to bridge the gap between research and practice (OPERAs[10]). The knowledge generated by those initiatives needs to be evaluated, synthesized and refined to take shape as readily usable standards.

3 The institutional gap to allow for change

Extensive research has recently focused on assessing the comparative efficiency of Gray vs Green Infrastructure. We argue that even if the efficiency of green infrastructure is demonstrated and convincing, this is not always sufficient to lead to change in investment decisions. This can be because the institutional structures in a given setting may not be conducive to facilitate such investments. For instance, the work of Mathews and Byrne on urban green infrastructure has highlighted that the existing path dependency in spatial planners decision making as well as them not being particularly keen on institutional innovation

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[6] http://www.ipbes.net
[7] http://biodiversity.europa.eu/maes
[8] http://invaluable.fr/
[9] http://www.openness-project.eu/
[10] http://operas-project.eu/

constitutes an obstacle to the development of GI (Matthews et al., 2015). To urge the widespread implementation of NWRMs, the European Commission (EC) has launched a number of initiatives on NWRM over the last few years. Additional efforts should therefore be made to raise awareness of decision-makers on the full potential of NBS. Those policy adjustments and enhanced coordination are seen as a pre-requisite for appropriate management decision and consequently for the NBS to be effective (European Union, 2014)

This correlates with the work of Mazzucato in highlighting the crucial role of public institutions and civil servants in the innovation process (Mazzucato, 2013). When looking through the lens of operationalization readiness of actors for change need to be separated from the capacity of the structure they are part of to accept and support this change. This includes both public and corporate institutions. As an example Richardson already identified that in the case of ecological restoration in Anglophile jurisdictions, present corporate norms and limited liabilities are an obstacle the for a wider development of NBS (Richardson, 2016). The institutions tasked with water management have been slow to embrace the NBS due to the lack of necessary changes in legislation in different countries, but the inertia of these mostly national institutions to expand and accept the new knowledge and build the capacity also presents a unique challenge, especially in SE Europe. The need for adaptive management and increased actions for DRR to increase resilience to climate change and the uncertain impacts of ongoing man made landscape transformation (van der Keur et al., 2016) provides a basis for stronger consideration of NBS as a credible component of DRE (Van Wesenbeeck et al., 2014). An example of legal evolution demonstrating this is the amendment of California’s public financing law stating “that source watersheds are recognized and defined as integral components of California’s water infrastructure” (Governor of California, 2015), thereby accessing similar selection and funding opportunities (Chiang, 2016). Finally we recognize that while formalized managerial approach might be attractive in adapting institutions, natural resources management needs shall operate to better accommodating a variety of partial and contingent solutions (Cleaver and Franks, 2005).

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3.1 Infrastructure gap

Assuming that for the implementation of NAS, NBS need to become part of the infrastructure planning processes of countries, a number of challenges lie ahead:

Firstly, societies have set very high standards and safety regulations for the “built environment” and the construction sector procedures primarily to prevent death and injury from accidents and disasters. This makes the construction sector a very conservative and risk avert sector where innovations take a very long process to be implemented and mainstreamed. Given also procurement and financing rules and corresponding economic incentives, only proven technologies are used in real scale projects so as to limit construction risks to a minimum. As reported by the 2016 WEF report “Shaping the Future of Construction. A Breakthrough in Mindset and Technology” compared to many other industries, the construction industry has traditionally been slow at technological development and has undergone no major disruptive changes (Wolrd Economic Forum, 2016).

Secondly, the traditional water management approach has been one of working against nature or to protect ourselves from nature; and just recently is changing to an approach of working with nature, living with and adapting to water commonly identified as adaptive water management (Pahl-Wostl et al., 2007). Water management has historically been dominated by individuals with backgrounds as civil engineers, whose training is in line with the risk reduction and safety and accuracy similar to the construction sector[11]. In contrast with grey infrastructure, NBS performance cannot be as easily engineered or measured with as much precision and is expected to have a rather cyclical nature.

Thirdly, the proposers of green infrastructure are often ecologists and biologists that have been trained within a very different scientific paradigm and speak a ‘different language’ than the key decision makers, who are often civil and financial engineers at the service of public authorities, contractors and financing institutions. Thus, even if convinced of the potential theoretical effectiveness of NBS and their long term contribution to flood and drought protection, these decision makers will often expect hard data and figures about different criteria, such as life cycle costs and total costs of ownership, that can provide results. Those proposing NBS, given their different research interest and bias, may fail to generate the type of data from the pilot studies that can be easily be transferred into the standard procedures of those of who would implement them at larger scales. This can limit the feasibility to design the equivalent to building codes, as well as standard risk and quality management approaches for the operation and maintenance phases of an NBS.

Fourthly, for NBS to be up scaled and become mainstreamed; they need to be procured following the same public procurement rules and contracting frameworks as regular infrastructure, and this in each of the life cycle phases. A key challenge for NBS posed by EU public procurement rule and trends in national procurement strategies is the need to define clear Key Performance Indicators and functional requirements on which to base payments to private contractors implementing NBS. This allows these strategies to be executed through performance based contracts. Additionally most EU governments have the

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[11] As exemplified at the Ukrainian Institute of Water Problems and Land reclamation were professional in charge of ecological restoration were formerly in charge of dam and grey infrastructure development. From interview carried out in January 2016

aim to keep their size limited and opt for procurement strategies that require limited in house personnel for their oversight.

The future of the infrastructure market cannot be seen as grey versus green, but rather a continuum from green to grey with many hybrid solutions. The combination of green and grey infrastructure to achieve specified levels of services poses a significant R&D challenge. This research challenge is already recognized by the EU water sector and mentioned in the recently published Water Supply and Sanitation Technology Platform (WssTP) Water Vision 2030 ‘The Value of Water: Towards a Future proof model for a European water-smart society’ (WssTP, 2016).

Focus of NBS pilots need to consider the concrete information needed by the actors responsible and liable for their implementation in their initial planning and design. A first step for this alignment is the creation of a common language between these different communities of researchers and practitioners.

3.2 The social integration to operationalize

Several scholars have argued that many policies to address climate-related risks management fail because they oversimplify or neglect the uncertainty and complexity associated with risk management systems (Borowski and Hare, 2007; Knüppe and Pahl-Wostl, 2011). The densely interconnected networks in which decision-actors operate, which span between and across ecological, economic and socio-political domains can create complexities and challenges the need to be considered. Uncertainty on how other decision-actors involved in the network will act make it very difficult to determine how effective a policy will be (Mingers and Rosenhead, 2001). Interdependency between actors influenced, behaviour of individual actors (e.g. farmer’s actions) which specific policies are targeted to regulate can increase unpredictability (Brock and Durlauf, 2001). Action choices are not neutral, but commensurate with the perspectives and frames held by the actors making the decisions. The problem is that when these frames do not overlap or are incompatible, they lead to a situation of ambiguity (Brugnach and Ingram, 2012).

In multi actors setting the presence of ambiguity may have diverse implications. On the one hand, a diversity in frames can offer opportunities for innovation and the development of creative solutions (Brugnach and Ingram, 2012). On the other hand, the presence of ambiguity can be a source of discrepancies or conflict in a group. When this happens, ambiguity can result in a polarization of viewpoints and the incapacity of a group to create a joint basis for communication and action, conditions that can greatly interfere with the development of collective actions (e.g (Brugnach et al., 2011)). The extent to which the lack of shared meaning alters the implementation of a project is largely dependent on the behavioural repertoires actors use to interact with one another (Donnellon et al., 1986). It has been suggested that divergent frames can still yield organized collective action when the interaction frames (i.e., communication behaviours actors use) are sufficiently aligned (Dewulf et al., 2009).

A sufficient overlap in interaction frames is a sine-qua-non condition allowing decision-actors with divergent problem frames to interactively co-construct overlap in their decisions; that is, to develop collective action. To this aim, ambiguity in interaction frames needs to be addressed through the creation of a collective decision-making environment in which the parties are fully aware of their role and the roles of the others in the interaction environment.

As formalized development of NBS is an emerging field of research, few studies have reported to date the actual acceptability of local population to NBS implementation. Alignment between local expectation and planned projects are known to be major obstacles to the development of other sustainable infrastructure as wind farms (Groth and Vogt, 2014; Perlaviciute and Steg, 2014). In the case of Blue-Green infrastructure lack of confidence on sociopolitical structures and public preference towards NBS have been shown to be a major barrier to implementation by Thorne et al. in the case of urban flood protection (Thorne et al., 2015). As for alternative energy strategies acceptability issues have only recently been included in global research agenda (Perlaviciute and Steg, 2014), we can only highlight its importance into green infrastructure development. Recently Derkzen et al. (2016) has demonstrated in the case of the Netherlands a positive correlation between knowledge of the adaptative capacity of NBS and societal preference for them versus other infrastructure development options (Derkzen et al., 2016). This shows that while the scale of acceptability issues might be unknown and culturally dependent, its impact on effective implementation of NBS can be pragmatically tempered through higher levels of stakeholder involvement from very early in the infrastructure planning phase so that they understanding of the way NBS solutions work increases and their level of control and risk perception decreases.

3.3 The finance gap

Climate adaptation costs for developing countries have been calculated by the (World Bank, 2010) to be between USD 70 to 100 billion from 2010 until 2050. The Global Canopy Foundation (2009) report a financing gap of US 90 billion for mitigation and adaptation to climate change (Global Canopy Program, 2009). And according to the World Bank approximately 85% of these funds must come from private finance (Baietti, 2012). For private or commercial finance to be part of the solution there are two ways: projects are undertaken and financed by the private sector on own initiative or projects are tendered by national governments as concessive or non-concessive Public-Private Partnerships.

The first option may apply mostly to climate mitigation and small adaptation projects in sectors such as agriculture which have a more private nature. Given that water security and services are often public goods; the second option is often the most applicable. Either way, for these projects to be financed and implemented by the private sector, they have to generate an attractive Internal Rate of Return.

A Public-Private Partnership is defined by the Canadian Council for PPP as a “cooperative venture between the public and private sectors, built on the expertise of each partners,that best meets clearly defined public needs through the appropriate allocation of resources, risks and rewards”. PPPs are financed making use of project finance where the only collateral for financers are the cashflows of the project.

As stated by Altamirano et al (2013) (Altamirano et al., 2013) green infrastructure climate adaptation investments due to their intrinsic characteristics present unique risks due to their cash profiles. They combine the challenges of regular climate adaptation as capital –intensive, unique, delayed and dispersed benefits, non-guaranteed and non-financial benefits, limited autonomous earning power and high risk profile with the characteristics of green infrastructure projects. This includes: elevated perceived risks, capital markets and information gaps due the “newness” of the technology and the perception of excessive risk. This can lead to a risk-reward profile that makes these projects not financially attractive, in absolute or relative terms.

To illustrate the differences between NBS (hybrid) solutions versus traditional grey solutions for flood control, the following qualitative graphs show qualitatively the comparison of these two in terms of required investments (capital and operative expenses) and in terms of the level of service they provide and the time it takes to reach the required level of service. As shown in the first graph, NBS may require similar capital expenses but spread over a longer term as they take longer to “build” than grey solutions, but are expected to require in the long term lower costs for their maintenance and operation. Equally NBS (hybrid) solutions required longer term (20 versus 5 years for mangrove restoration and groins versus seawalls) for their implementation and therefore longer term to reach the required level of service.

Both characteristics are problematic for standard project finance loans; as the construction phase is perceived as the most risky phase and private contractors start to get paid only once the infrastructure is operational and delivers the specified level of service.

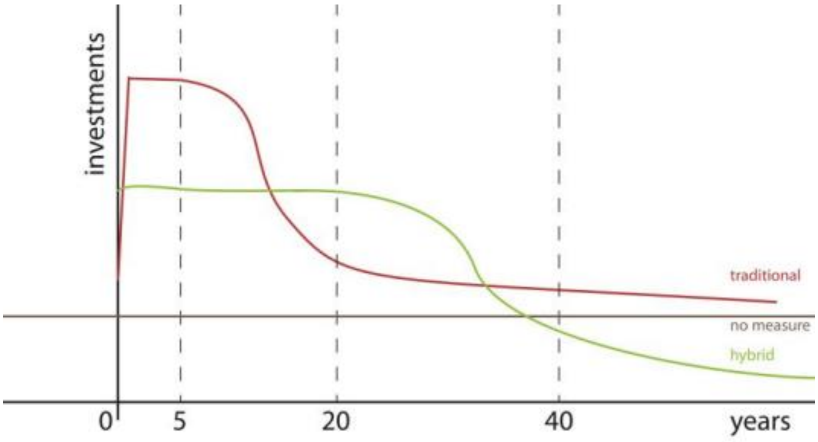

Figure 3: Grey vs Green Infrastructure qualitative capital investment and operational expenses required. From Altamirano et al. (2013) (Altamirano et al., 2013)

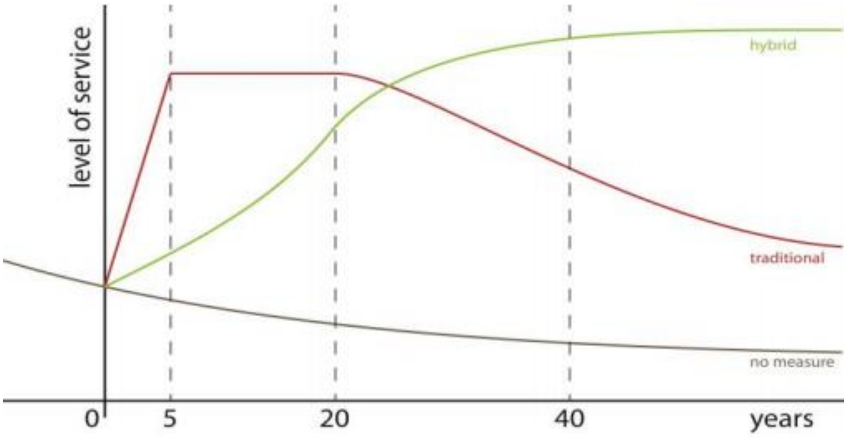

Figure 4: Grey vs Green Infrastructure time required to achieve specified levels of services. From Altamirano et al. (2013)

The World asserted that the consideration of externalities and non-monetized benefits may provide the greatest opportunity to fill the viability gap in low carbon and sustainable investments (*Green Infrastructure Finance: Framework Report*, 2012). Insurance value is argued here as a key benefit that can be included to increase viability.

Climate bonds are an increasingly attractive way to channel finance to climate adaption, but bonds may solve the short term financing gap but not the long term funding gap. The real challenge remains on improving the business case and the cash flow profile of NBS projects, so that the issuers of bonds are unable to pay them back upon maturity. This challenge is at the core of our NAS approach.

4 Method

The method presented here aims at assessing the opportunity of NAS in the context of water related DRE up and to mainstreaming the adoption of these types of solutions on territories. It matches the previously identified gaps with operational steps. The Framework is the result of the confrontation of imperative challenges faced and limitations of researchers, NGOs, public bodies and design agencies. It was conceived as a current roadmap to identify the fastest route and best practices for concrete operationalization. With the identified research gaps being further refined, the framework should be further updated, with a value directly dependent on the amount of empirical evidence that will populate it. It is assumed that the shift of NBS in the global infrastructure investment will expand the available data over time. As such it is yet a conceptual work of synthesis between fields afferent to the shift of infrastructure design and implementation. The framework takes the standpoint of a NAS project developer outside of a research context. All steps are considered as potentially done independently from public institutions, either by NGOs, Research institutes, Private entities or individual subcontracted within the scope of a diagnosis. As such the proposed framework differs but does not oppose to the Integrated Water Retention Measure Planning Cycle as presented in Figure 6. The difference arise from our focus on the “IWRM Plan” and its subdivision into interacting assessments. We also part from the cyclic representation, not because a consideration that there is a final point given to a NAS, but because triggering the development of a new plan does not necessarily engage the same developer as only the public institutions are bound to be consistently represented.

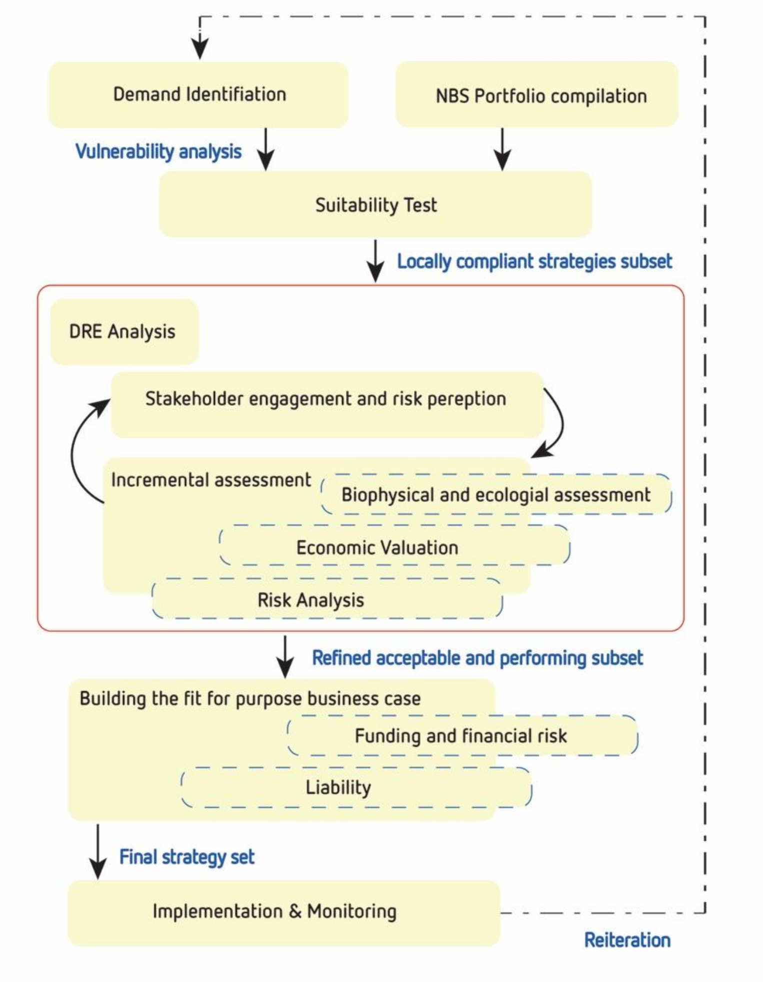

Figure 5: Stepwise development process for NAS

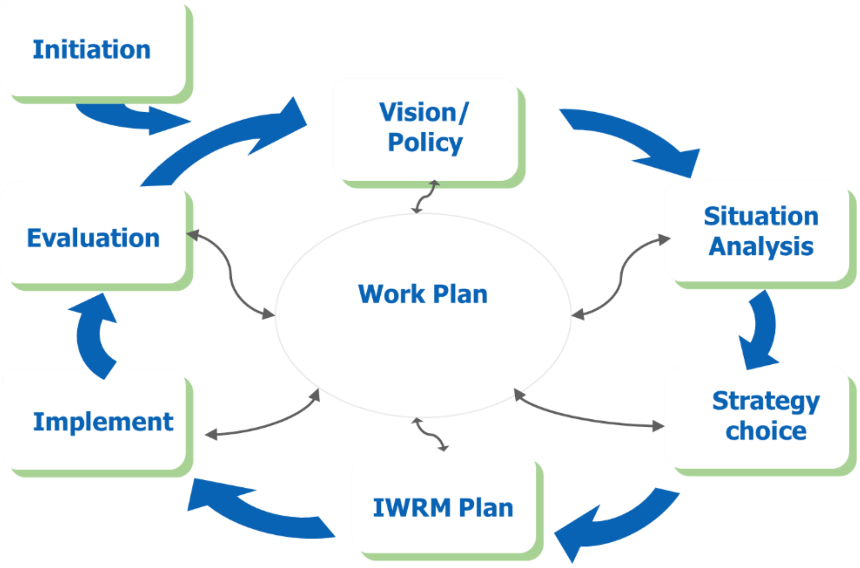

Figure 6: IWRM Planning cycle. Source: Capacity Development in sustainable Water Management (Cap-net,UNDP)

Phase 1: Demand identification

The framework starts from the point in time where public institutions -or large private landowners - formulate the need to develop or maintain the assurance capacity of a given territory. In Phase 1, the ecological as well as socio-economical systems are defined. At that stage, the procuring entity may only scope for the level of service needed, and may include, if necessary, a mapping of the existing level of services. The project designer should include identification of property rights and the legal framework related to the project, we consider here only local regulations and existing payment schemes. Those studies aim at defining the demand for services. Thereby the whole development of NAS fits into a wider service scheme that overlaps infrastructure as well as social set-up provision. To place it into context, this steps would occur after the “Initiation” and the “Vision/Policy” (elsewhere called “commitment”) part of the IWRM planning cycle. A key difference is that the authors consider in the case of NBS only partial commitment is necessary due to the practical or financial incompatibility of NBS and desired outcomes in some cases. The Demand identification phase therefore corresponds to the “situation analysis”. Similarly, the “strategy choice” is not included as it does not lay in the hand of the developer. The importance of recently developed decision scaling in defining desirable outputs acceptable threshold from the procurer’s point of view is however stressed (Poff et al., 2015).

Phase 2: NBS portfolio compilation

Phase 2 corresponds to the compilation of existing data to characterize an NBS. Those data are used to qualitatively map the boundaries of NBS service provision for DRE. This would correspond to the pre-scoping phase and requires use of readily available tools and standards methodologies. The authors acknowledge the difficulty to access such information due to the present lack of structure in NBS industry as well as scientific knowledge gaps. As such the greatest benefit would arise from open web platform allowing professionals to navigate within the existing state of art. We argue that this step does not usually appear in grey infrastructure planning only because the predictive capacity of engineered solution allows developer to design in-house with readily low tolerance[12] in service provision.

Phase 3: Suitability testing / screening

While the advantages of NBS can be numerous, they are not universally applicable. It has been indicated that the implementation of NBS would benefit from integrated spatial planning early in the planning process and that it is necessary to work at the landscape level to ensure the enhancement of ecosystem health and resilience (European Commission, 2016; Naumann et al., 2011). Therefore, we propose suitability testing to be the next step in the NAS development process.

However, thorough understanding of the existing conditions and required services on the one hand and in-depth knowledge of the available, state-of-the-art NBS on the other, is required to effectively predict the best possible results. Thus, in the 3rd phase of NAS development, the set of strategies identified in the 2nd Phase is reduced by comparing them with the 1st Phase

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[12] Defined here as in engineering as the potential margin between intended and actual value.

requirements. This phase results in a subset of strategies based on NBS that are acceptable for the stakeholders. This could range from ecosystem conservation or restoration scenarios. In practical terms, this pre-scoping can also be carried in parallel with or as a replacement for the 1st phase in certain cases. For example, this is possible if the legal context is already characterized or solutions to use are already predetermined in the request for proposals. In this case, the commissioning body has already performed the first two steps and thus all required information is already available for suitability testing. Another scenario where this could done is if there was a highly competitive context, where risk-prone actors would carry out tasks in parallel to remedy the unfavorable conditions as soon as possible.

Phase 4: Disaster Resilience enhancement analysis

Phase 4 corresponds to the evaluation phase of traditional infrastructure projects where quantitative impact evaluation is performed. Focus is placed on the potential of co-construction and feedback loops to improve risk perception and consequently to allow for more effective valuation of the insurance value in a DRE framework. As such the authors follow the new environmental governance position that complex policy goals need increasingly decentralized and participatory measures rather than coercive actions (Holley, 2010). Thereby parameters are progressively refined and are used to interactively highlight hidden tradeoff from various stakeholders point of view. The number of iterations between phase 4.1 and phase 4.2 is decided by the project designer to decide based on local conditions. The following aspects are quantitatively assessed and ranked (when possible) in the project design:

- Expected cost-benefits (including economic impact at landscape scale) and resulting value-for-money comparison.
- Resilience Enhancement or Risk Reduction in the case of too large data gaps
- Contribution to national and local targets (resources conservation, water quality, biodiversity, land use, etc.) and relevant regional/global ones (e.g. EU).

- Expected service provision changes and climate robustness.
- Co-benefits.
- Monitoring plan (with associated costs and identification of existing capacity).
- Risk perception

In this phase possible strategies shall be co-designed and tested using for example the vulnerability cube by Fraser et al (2007) (Fraser, 2007). The cube as a visualization approach integrates a variety of socioeconomic and environmental variables into a unified assessment. The aim is to reflect the multi-dimensional, interdisciplinary nature of vulnerability and to analyses the governance performance of disaster strategies in time.

Phase 4.1 Stakeholder engagement and risk perception

Social networks can play a critical role to ensure the consultation of ethical issues in the protection and use of ecosystems and the distribution of access to their servies (Jax et al., 2013). During the design of an NBS, social networks can be engaged to identify and manage tradeoff and consequently improve acceptability of the NBS. This can improve the resilience and efficiency of the ecosystem by making the most of social capital (Wolf et al., 2010) contribution to climate change adaptation. In order to guarantee an effective and long term involvement of stakeholders for NBS implementation, a methodology based on two main activities:

Mapping and analysis of network interaction complexity. The mapping and analysis is done for both institutional and non-institutional actors involved in a risk management decision-making process. This assesses how the information flows within the network, and at disclosing the interaction mechanisms involving the different actors (i.e. cooperative task performance). A Social Network Analysis (SNA) approach is applied to better comprehend the actual role played by the different actors in risk management, the tasks performed and the information each actor brings into the network. The SNA allowed to identify the potential vulnerabilities in the interaction network.

Collection and structuring of risk perception. A storytelling approach (SA) and problem structuring method, specifically Mental Model of System Dynamic (MMSD), is implemented. The MMSD allows to structure the actors' understanding of the risk situation, and to identify the main differences (ambiguity analysis).

Among the different methods available in the scientific literature for modelling and analyzing the social networks, an example is the Organizational Risk Analysis (ORA). The underlying assumption in ORA is that an organization could be conceived as a set of interlocked networks connecting entities such agents, knowledge, tasks and resources. In order to implement this approach, we considered the whole set of actors involved as one heterogeneous organization. The interlocked networks can be represented using the meta-matrix conceptual framework, as shown in the following Table 1 for the case of flood risk management.

	Agent	**Knowledge**	**Tasks**
Agent	*Social network:* map of the interactions among the different institutional actors in the different DRR phase	*Knowledge network:* identifies the relationships among actors and information (Who does manage which information? Who does own which expertise?)	*Assignment network:* defines the role played by each actor in the DRR phases
Knowledge		*Information network:* map the connections among different pieces of knowledge	*Knowledge requirements network:* identifies the information used, or needed, to perform a certain task in the DR
Tasks			*Dependencies network:* identifies the work flow.

			(Which tasks are related to which)

Table 1: meta-matrix conceptual framework

The analysis identifies the key elements in the network and the main vulnerabilities. To this aim, graph theory measures are implemented. Table 2 describes the measures adopted for the identification of the key actors, their definition according to the graph theory and the meaning in emergency management.

Network	**Network measure**	**Assessment**	**Meaning in DRR**
Agent x Agent	Total degree Centrality	Those who are ranked high on this metrics have more connections to others in the same network.	Individuals or organizations who are 'in the know' are those who are linked to many others and so, by virtue of their position have access to the ideas, thoughts, beliefs of many others.
	Betweenness centrality	The betweenness centrality of node v in a network is defined as: across all node pairs that have a shortest path containing v, the percentage that pass through v.	Individuals or organizations that are potentially influential are positioned to broker connections between groups and to bring to bear the influence of one group on another or serve as a gatekeeper between groups.
Agent x Knowledge	Most knowledge	Assess the number of links between a certain agent and the different pieces of knowledge in the network.	An agent with a high value of most knowledge has access to a great variety of knowledge to be used in case of disaster.
Agent x Task	Most task	Assess the number of links between a certain agent and the different task that need to be carried out for risk management.	An agent with a high degree of most task plays a crucial role in the network due to her/his capability in performing different tasks.
	Total degree of centrality	It calculates the importance of a certain piece of information	The most central pieces of knowledge are those whose availability is crucial

Knowledge x Knowledge		according to the number of connected links.	to make the other pieces of knowledge accessible.
	Closeness centrality	Closeness is the inverse of the sum of distances in the network from a node to all other nodes.	The closeness centrality measure allows us to identify the information that could facilitate the process of information sharing.
Knowledge x Task	Most task	Assess the number of links between a certain piece of knowledge and the different task that need to be carried out for risk management.	The pieces of knowledge with a high value for this measure are fundamental for the effectiveness of the network, since without them a high number of tasks will be not carried out.
Task x Task	Total degree of centrality	It analyses the complexity of the connections within the task X task network.	Tasks with high degree of centrality are those that have to be carried out in order to allow the executions of the other tasks.

Table 2: Graph Theory measures for key element detection

Network vulnerability, elements that could lead to failures of the network, lower performance, reduced adaptability, reduced information gathering, etc.

The second phase of the methodology aims at spelling out the different frames that decision-actors hold regarding the risk management and the dynamic behavior of the system. In this work, frames are represented as mental models. We assume that a mental model is built of causal knowledge about how a system works and evolve in time (Sterman, 1994). Following (Schaffernicht and Groesser, 2011), we refer to these models as Mental Model of Dynamic Systems (MMDS). According to this definition, a mental model is capable of representing the perceived cause-effect chains influencing the dynamic evolution of a system (Jones et al., 2011) The results of interviews are structured in a Causal Loop Diagram (CLD). CLD are tool for representing the feedback structure of systems being modelled (Simonovic, 2011).

An ambiguity analysis is implemented to analyze how ambiguity in risk perception can or does inhibit collective decision-making. It compares the decision-actors' understanding of the system dynamic. For this reason, a pairwise comparison is implemented among the different decision-actors, considering their understanding of the problem core elements, the dynamic evolution of the system and the drivers influencing the system dynamic. To this aim, the MMDS comparison method described in (Schaffernicht and Groesser, 2011) can be implemented.

Phase 4.2: Incremental assessment

This phase aims at demonstrating the service delivery potential of NAS. It builds on an interdisciplinary assessment that could be presented as a multicriteria assessment. It starts from a comprehensive mapping of hazards and exposed assets. Then it integrates different economic development and climate impact scenarios combined with a cost/benefit approach (discounting capital and operational expenditures over time, compared to discounted averted damages) to assess the subset of NAS strategies. As highlighted by David Bresch, a consistent application of assessment would require at this stage common assumptions used to forecast economic and population growth (Bresch, 2016). Such a standardization would need to be operated throughout the research community so that future project developers, clients, beneficiaries and investors are able to compare study cases. It is therefore beyond the scope of this work to provide a judgment on best type of assessment as any ranking would be highly dependent both on data availability, time and budget available to the developer. We here take through the limitations of those methods as a snapshot of current possibilities available to navigate through the difficult task of the assessment.

4.2.1 Biophysical and ecological assessment

The biophysical and ecological conditions for NBS to increase resilience in rural, peri-urban and urban settings are considered in an integrated fashion following a source-to-sea approach (Basin scale). At the geographical level, this approach seeks to connect resilience towards flooding and drought at various spatial scales, e.g. the urban environment surrounded by peri urban and rural areas.

As such we argue that assessment transfer can only be realized towards external, non-research project developers in the case of extended availability of basin-scale monitoring data. For a real-life project assessment to be feasible, we consider that different actors can only take over a limited number of tasks. An analogy can be drawn with renewable energy projects, where long term pre-project assessment are realized by project developers –e.g wind resource-, but these can only bear fruits with pre-existing large scale an long term data –e.g national wind atlas. Without this possible correlation, we argue that the additional cost of assessment –or the risk to invest in it- may severely undermine NAS practical feasibility.

The resilience towards flooding in cities downstream in a catchment is dependent on interactions with river discharge and elevated groundwater levels that may burden drainage systems and cause groundwater flooding. For coastal cities, discharge is also dependent on coastal water levels, likely aggravated by sea level rise (Werner and Simmons, 2009). The trend of continuous growth of the larger cities and their densification leads to larger areas of paved soils and larger areas of roof tops, both of which hinder water from seeping into the soil, and contribute flooding risk in urban areas. In addition, roof materials, and infrastructure materials such as tramway catenaries are sources of potentially harmful metals to storm water drainage. Improved knowledge on biophysical and ecological properties at the spatial level of the catchment and at embedded levels as well as design of monitoring networks is crucial for the development and implementation of nature based solutions and consequently for a correct developing of NAS. This dependency to the very local context –up to a per asset level- requires downscaling the analysis to the city level. As identified previously by the insurance sector, this supports why biophysical and assessment can only render resilience by taking full account of anthropogenic constructions –including geology.

We argue that for optimal project development, ecological assessment must include species migration model runs, as climate change is expected to lower resilience of certain assemblage.

It is consider that this modelling capacity is achievable as already used for various agricultural activities (.eg wine (Hannah et al., 2013; Mosedale et al., 2016)). However numerous sites including species whose characteristics are not well known will realistically not be able to provide modelling with an acceptable level of uncertainty within the time frame and budget constraints of an infrastructure development. While some sites may be able to develop complex species and individual based and distribution models (Stillman et al., 2015), impact assessment as in the case of Wind farms development often relies on simple inventories and a few carefully designed observations campaigns, In such cases priorities given by the commissioner of the project as well the respective protection given by precautionary principle will be the only guiding principles for the developer in choosing his assessment methodology. The authors use this example to alert against reliance on any tool, as a simple species inventory with proper expert judgment may often be not only the only true possibility but a reliable choice (Teck et al., 2010). Ecosystems health shall be assessed following ecological restoration indicators as widely discussed academically (Pander and Geist, 2013). The geology, both natural and anthropogenic, below the urban environment constitutes part of the biophysical environment and knowledge on this is already giving birth to standardization process as the restore rivers wiki[13] or the REFORM European FP7 project[14]. Geophysical and ecological cross-analysis must also be a required to adequately design nature based solutions, e.g. identify locations where green infiltration, blue and grey infrastructure solutions are feasible and insurance value can be determined. Part of this assessment, e.g Wetland retention and aquifer storage, but also contaminants in infiltrated water and channeled water (blue) in and outside urban areas need to be considered for ecological assessments (Hamadeh et al., 2014).

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[13] https://restorerivers.eu

[14] http://www.reformrivers.eu/

4.2.2 Economic assessment (EA) and analysis

Economic valuation is first a tool for project selection. The economic assessment e.g. with Cost-Benefit analysis (CBA) from the public point of view enables both to state whether there is a collective interest to adopt NAS and to compare or optimize alternative NAS strategies. Included in this problem is the private or project level EA of NAS, which excludes social costs or benefits. The aim of such an EA is not only to identify, measure and compare these costs and benefits but also to support a debate on the distribution and dissymmetry of cost and benefits among stakeholders. In this sense, it can assist the project developer to identify potential partners of the project: co-benefits that the EA will identify or measure should indicate which parties might be willing to participate in the project.

The economic assessment accounts the costs and benefits of the NAS compared to a reference situation. In short it discounts capital and operational expenditures over time, compared to discounted averted damages and benefits. The insurance value can be defined as the difference in damage protection and resilience level between a NAS strategy and a reference strategy. Several particular stakes are worth mentioning to conduct relevant economic assessment in this framework.

Defining the damage cost (or avoided benefits once compared to a reference situation) is already a challenging task. However, as mentioned before tools and references exist, for some used and developed by the insurance industry. Damages assessed by insurance industry are *per se* restrictive because all damages, for instance indirect damages, are rarely insured and are very difficult to assess. Irrevocable losses[15] are also not insured, because out of the scope of the insurance industry.

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[15] irrevocable loss [German: unersetzbarer Verlust],losses are those that cannot be re-stated but might only be compensated e.g. loss of glaciers (due to warmer climate) or),loss of coastal land (due to sea level rise) or loss of precipitation (due to changed weather patterns). can only be compensated for, not re-stated or re-placed. Risk management options such as intervention or sharing of risk can only deal with some of the consequences of the loss, not the loss itself.. Irrevocable losses are uninsurable - still, some of their consequences can be insured (e.g. glacier melt is not random, hence cannot be insured, but the risk of a glacier lake bursting can be insured, since it's a random event.

Ideal assessment increased resilience value (and not only risk reduction) raises a new challenge for the economics research agenda. First idea is to consider that resilience enhancement will enable to limit future damages by increasing the pro-active adaptation as well as the reactive adaptation (Graveline and Grémont, n.d.) and potentially the bounce forward capacity. Bounce forward capacity is the notion that the affected system takes the opportunity to recover at a higher level of activity or efficiency than the reference state after a given event (Manyena, Siambabala et al., 2011).
The principle of the ES approach is to value in monetary terms the different ecosystem services associated with the NAS strategy compared to a reference (e.g. grey infrastructure) strategy that would provide lesser ecosystem services. Nature based solutions are per se implying more ecosystem service provision than artificial grey infrastructure strategies at the cost of primary service provision or operability. Transaction costs are to be included. As they have been shown to be underestimated for instance in the case of ecological restoration (Iftekhar et al., 2016) and can significantly impact the project financial viability.

Another challenge for a correct economic assessment is the NBS different dynamics and lifespan (see Figure 4 and part 3.4). Considering a short time span for the EA would disadvantage NAS solution compared to reference solutions. Following this consideration, the comparison of strategies can only be performed if grey and mixed set-ups are required to present EA with time horizon (or full life cycle costs) matching growth and stabilization patterns of ecosystems. While this shall positively contribute to a shift towards long term planning and investment within society, it still faces the choice of the time reference as ecosystem performance may take half centuries to fully develop (Moreno-Mateos et al., 2015). Discount factors are also a source of debate among economists as they have a significant impact on

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Likely: sea level rise and the loss of coastal land cannot be insured, since it's not random - but storm surge risk can be insured, since it's a random event).

the relative valuation of short term versus long-term costs or benefits. For instance the French report on public investments (Quinet, 2013) suggests 2.5% and 1.5% after 2070.

Uncertainty is obviously a limit to classical CBA or EA. In our case, the present limit of ecosystem resilience predictive capacity, as detailed e.g (Hipsey et al., 2015) for aquatic ecosystems, embeds uncertainty in the foundation of NAS CBA. In the context of hydro meteorological risks, uncertainty is particular evident and agreed upon in climate change studies (Hallegatte, 2009), but global changes also imply other uncertainties which can by far outweigh climate change impact (such as e.g. land occupation which will be a major factor in damage assessment or population concerned). According to the characterization of uncertainty different adaptations of classical deterministic EA can be adopted from stochastic or Bayesian CBA to real options. Grelot et al. (2009) (Grelot, F., Bailly, J. S., Blanc, C., Katrin, E., Mériaux, P., Saint-Geours and Tourment, 2009) shows for instance the impacts of uncertainty on flood damage reduction strategies CBA.

4.2.3 Risk analysis:

In the context of Risk analysis, NBS exhibit different Risk and Resilience function that what professional are typically used to. On the other hand it is required that the analysis fits into already existing scheme. On practical terms, we consider that the required climate knowledge to tackle climate related risk outweight their transaction cost and their potential to be misleading due to limitation of the decision space by Global Circulation Models. As such we pledge for standardized robustness analysis based one earlier conceptualization by (Lempert and Schlesinger, 2000) and its adaptation to water infrastructure investment by (Ray and Brown, 2015). As an extension of this we pledge for an application of the two core decision making elements presented in the Climate Risk Informed Decision Analysis (CRIDA), namely Decision scaling –presented in the Phase 1- and Adaptation Pathways as described by (Haasnoot et al., 2013). In this regard, the real options economic assessment presented above can be implemented to value the flexibility of the timing of decision or flexibility of design which could be particularly be useful in an adaptation pathway perspective. Out of the scope of the consideration of a wide range of pathways, the decision process remains in the hand of the procurer and falls outside the scope of this work.

Following the analogy and junction between green and grey solutions towards unified infrastructure conception, the risk analysis must address the main hurdles of Public Private Partnerships (PPP). Within the priority risk factor list[16] derived by (Ameyaw and Chan, 2015), two that shall have specificity to NBS are conflict between partners–addressed above-, and financing risk discussed in the next phase.

After completion of the Co-construction cycle, the NAS leaves a subset of socio-technically feasible strategies which are in phase 5 confronted with economical and financial context.

5. Building the fit for purpose business case

5.1 Funding and Financial risk

The construction time and the cyclical performance of many NBS solutions require a different financing model than traditional grey infrastructure; equally climate adaptation projects require a different approach. When opting for project finance and PPP's as project delivery and finance methods is of even greater importance to:

- Define clear performance indicators and functional requirements
- Adapt payment mechanisms to recognize the cyclical fluctuations in performance cause by natural processes
- Implement risk sharing facilities that offset the additional risks introduced by the novelty of NBS versus grey

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[16] "poor contract design, water pricing and tariff review uncertainty, political interference, public resistance to PPP, construction time and cost overrun, non-payment of bills, lack of PPP experience, financing risk, faulty demand forecasting, high operational costs and conflict between partners"

The Financial risk is then highly linked to the presented issue of financial valuation, where process depends on the type of DRE considered. In practical term, the risks of financing a floodplain widening and maintenance for flood protection will depend on a the combined uncertainty of ecological and actuarial sciences, while the risk for a similar area for groundwater recharge is highly dependent on enforcement efficiency and valuation of water services provided by natural sciences and GIS processing (Grygoruk et al., 2013).

5.2 Liability

One of the limiting factors for widespread implementation of NBS is the limited trust and potential concerns on liabilities linked to the actual protection granted by NBS in case of natural disasters. The question of liability and enforcement then becomes intrinsically linked to the contractual format of the chosen NAS. In the case of an aquifer recharge for protection of strategic resources -e.g regulating water consumption and industrial output- the diversity of potentially impacting actors -e.g farmers- raises the concern of opportunistic behaviors as payment scheme early exit. In this extreme case, a little number of “free riders” in the case of non-compliance can seriously hinder the performance of the whole NAS. In a less extreme case, contractual control of flood-plain, through payment for ecosystem services, can more directly relate to the existing work on long-term procurement of conservation auctions. As studied by Di Corato et al.,success of those scheme requires first and foremost strong enforcement of contract deadlines, and second carefully selected exit options, which only deliver benefits when designed considering contractors commercial changing trade-offs -eg. change in agricultural output prices (Corato et al., 2015).

Phase 6: Implementation

Aside from the regular consideration on monitoring the works of development of the NAS, monitoring plays a key role in NBS performance. As described above, implementation resulting in resilience enhancement depends on stakeholders’ awareness and engagement.

Implementation must therefore ensure a sustained risk awareness over the whole life cycle of the scheme, which can encompass multiple generations for classical infrastructure investment, and then even longer if considering a new ecosystem development (Moreno-mateos et al., 2012). Moreover, the intrinsic continuous self-reorganization of ecosystems requires a throughout adaptive management, as the insurance service provision is dependent not only on the ecosystem health, but species assemblage and spatial evolutions.

The IWRM planning cycle presents the milestones “Implement” and “Evaluation”. Past this point, monitoring threshold would lead to reiteration of the cycle towards potential alternative pathways –or more simply triggering of new actions- .

5 Discussion :

The presented framework paves the way for an industry of NBS project development harvesting their insurance value. We follow the task and work structure of other industrial groups to highlight to different stakeholders group the minimal requirements for operationalization. We argued that NAS development contributes to fitting new modelling and simulation techniques –without specifying them- for highly complex systems in a fit-for-purpose perspective and equal ground comparison of grey and green components of complex infrastructures. As direct consequences NAS focus knowledge production to design science and policy required for insurers and the insured to recognize the value of these assets and direct financial capital towards their better management. The main advance expected is the development of resilience engineering and approaches for communication which can bridge the gaps between key stakeholders, being the main leverage for DRE. While gaps are identified to fit in a future development model, barriers remain to their implementation beyond the gaps described.

Foreseen difficulties to implementing NAS:

Society resilience and ecosystem resilience may widely differ(Cumming, 2016) –e.g as arid lands resulting from desertification may be very resilient states. In this case, as demonstrated for low resilient ecosystems, insurance value can be negative (Baumgärtner and Strunz, 2014), and informed management decision must be taken away from the flare of resilience. As we have seen that the characterization of resilience over different scale and their corresponding hysteresis effects are still a major challenge, we argued that a similar shift to robustness may prove a key step to answer predictive power obstacles already identified by (Groffman et al., 2006) and recently reaffirmed as major ecosystem management challenges (Sasaki et al., 2015). It would reinforce the exchange between infrastructure industry and socio-ecological stakeholders as already adopted by the World Bank for Water infrastructure investment (Ray and Brown, 2015). This “useful resilience” awareness as well as design new business models require an important shared knowledge. The lack of permeability between expert groups will be an obstacle not directly addressable by research work, not only by limiting technical and financial exchanges, but by leaving non-experts out. Beside the benefits of collective development, NAS does not provide solution to solve access to land rights and solve local conflict of interest. This plays a crucial role as most of eligible land surface for NWRM is in private hands and distributional problems might arise when looking at the benefits and costs.The authors argues that this cannot be accounted as septicity of NAS as farmers have been identified as major stakeholders in biodiversity governance (Hauck et al., 2016). Similarly NAS would tend to increase the power position of landowners rather than reversing existing power relations. This last aspect need further research.

Contingent to the limits of interdisciplinary exchanges, structures which combines all the required knowledge to oversee a full NAS development are yet lacking. This transitory obstacle can be illustrated by the underrepresentation of applied economic knowledge in restoration practice that leads to a widespread and harmful underestimation of transaction costs (Ahmad and Gabbouj, 2011). On a short term, this can be overcome by capacity building programs between countries where specific regulations have already created a structured natural infrastructure industry -e.g Australia with PES scheme or US with Biodiversity offsets.

- Potential Impacts and pitfalls:

The impact expected to NAS development is twofold. In a first time to help package interdisciplinary research content into usable tools and data specifically for practitioner. In a second stage, to improve co-creation of knowledge such as Grey and Green infrastructure common permitting procedure, comparable standards for performance and inclusion of NBS into DRR and DRE public and private investment.

On the other hand, the incremental assessment and cooperative modelling, while improving fit to local requirement and projects bankability, may significantly increase the cost and duration of preliminary studies. However we argue that wind power development has proven that when permitting procedure and possible incomes are well defined, differences in planning systems and financial support mechanisms have less impact on deployment than landscape protection and local ownership patterns (TOKE et al., 2008). Similarly, concern may be raised as to the low visibility on future conditions that adaptive management and changing ecological conditions -described for riverine and wetland ES management (Gunderson et al., 2016). We argue that those adverse effects on stakeholder participation can be overcome by including a wide variety of adaptive pathways from the first iteration of the iterative process as well as in the final project. In the case where NAS include a protection through risk transfer, the authors acknowledge the risk for NBS or mixed solutions managers to opt out of some nature management requirement, therefore creating potential new vulnerabilities. Similarly, the Insurance value cannot be seen as a global game changer for ecosystem services based projects as it has been shown that it is irrelevant to risk-neutral or risk loving individuals (Baumgärtner, 2007).

Agenda for future research & development

The present work presents NAS development under an infrastructure lens. The next stage is to ensure that liability criteria for Grey, Green and mixed infrastructure are consistent for without it no decision making can be made on equal grounds. From this naturally follows that standardized performance and service provision (expected co-benefits and risk reduction) forecast must be developed for NBS. An important milestone shall be a track record of threshold assessment and corresponding early-warning systems. As confirmed in a recent white paper, business cases emerge proving the commercial viability of NBS and recommending that green infrastructure solutions should become part of the standard toolkit for modern engineers (The Nature Conservancy, 2013). Now still remain the tools to incentivize those choices as often while NBS can provide non-substitutable services, their private value creation intensity may only seldom compete with intensive industrial use –e.g a real estate development versus a forest. The challenge here is to correctly assess the social value of those ecosystem services and match it with institution able to internalize it. As such we pledge for a continuation and development of legal tools to provide NAS solution leverage for their provision of multiple goods and services.

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