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CLIMATE AND DISASTER RISK ANALYTICS TOOL FOR ADAPTIVE SOCIAL PROTECTION

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CLIMATE AND DISASTER RISK ANALYTICS TOOL FOR ADAPTIVE SOCIAL PROTECTION

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Table of Contents

Figures 4

Tables 5

List of abbreviations and acronyms 6

Executive Summary 8

Ringkasan Eksekutif 9

1. Introduction 12

1.1 Problem statement and rationale of the study 12

1.2 Risk framing 13

1.3. CADRAT-ASP case study specification 15

2. Data and information needs for risk assessments in the context of ASP 19

2.1. Exposure 20

2.2. Vulnerability 23

2.3. Impacts 26

2.3.1. Impact chain methodology 28

2.3.2. Impact chain for exposed post offices and state-owned banks and services 30

2.4. Summary of main results on risk and impacts 34

3. Quantifying climate impacts on social protection dimensions: a proof of concept 36

3.1. Framing climate risk analytics for the ASP context 36

3.2. Quantifying exposure and vulnerability: social protection dimensions 38

3.2.1. Impact on Income 40

3.2.2. Impact on access to health services 48

3.2.3. Impact on access to education 54

3.2.4. Impact on mobility 59

3.3 Findings on the feasibility of quantifying ASP with ECA 65

4. Conclusion and Recommendations 67

4.1. Conclusion 67

4.2. Recommendations 68

References 74

Figures

Figure 1: Risk as a result of its subcomponents – hazard, exposure and vulnerability 14

Figure 2: Location map of the case study region, Nusa Tenggara, in Indonesia. 17

Figure 3: Exposure categories 21

Figure 4: Vulnerability categories 24

Figure 5: Impact chain approach of this study. 28

Figure 6: Impact chain for the risk of tropical storm winds to post offices/ state-owned banks and services 30

Figure 7: Overview of the ECA framework with inputs and outputs for CLIMADA 37

Figure 8: Selected social protection dimensions (non-tangible assets) for this proof of concept 39

Figure 9: Number of people living in the lowest income group 43

Figure 10: Impact on Income. 44

Figure 11: Access to health services 50

Figure 12: Impact on health-care centres. 51

Figure 13: Impact on access to health services. 53

Figure 14: Access to education: Grey points indicate the location of an education facility. 56
Figure 15: Impact on access to education for students 58
Figure 16: Access to transportation. 62
Figure 17: Impacts on mobility. 64

Tables

Table 1: Overview of literature reviewed to identify exposure factors, vulnerability factors and intermediate impacts 19
Table 2: Selected exposure factors for the impact chain analysis and their relevance for ASP in Indonesia 29
Table 3: Four income classes 42

List of abbreviations and acronyms

ASP	Adaptive Social Protection
BLT	Bantuan Langsung Tunai (Direct Cash Assistance Programme)
CADRAT	Climate And Disaster Risk Analytics Tools
CCA	Climate Change Adaptation
DRM	Disaster Risk Management
ECA	Economics of Climate Adaptation
GAR	Global Assessment Report
GEG-2015	Global Exposure database for GAR 2015
GIS	Geographic Information System
GFDRR	Global Facility for Disaster Reduction and Recovery
GPFI	Global Partnership for Financial Inclusion
HEVA	Hazard, Exposure and Vulnerability Assessment
ICT	Information and Communication Technology
IPCC	Intergovernmental Panel on Climate Change
KPS	Kartu Perlindungan Sosial (Social Security Card)
MCII	Munich Climate Insurance Initiative
MSME	Micro, Small and Medium Enterprises
NGO	Non-Governmental Organization
NTB	Nusa Tenggara Barat (West Nusa Tenggara)
NTT	Nusa Tenggara Timur (East Nusa Tenggara)
OECD	Organisation for Economic Co-operation and Development
PDNA	Post Disaster Needs Assessment
PKH	Program Keluarga Harapan (Family Hope Programme)
PKPS BBM	Program kompensasi pengurangan subsidi bahan bakar minyak (Compensation program for reducing fuel subsidies)
PT Pos	Perseroan Terbatas Pos Indonesia (Indonesia's state-owned post office company)
SP	Social Protection
SPD	Social Protection Dimension
TNP2K	Tim Nasional Percepatan Penanggulangan Kemiskinan (National Team for the Acceleration of Poverty Reduction)
UNDRR	United Nations Office for Disaster Risk Reduction
UNISDR	United Nations International Strategy for Disaster Reduction
UN OCHA	United Nations Office for the Coordination of Humanitarian Affairs
UNU-EHS	United Nations University – Institute for Environment and Human Security

Executive Summary

Adaptive Social Protection (ASP) as discussed in this report is an approach to enhance the well-being of communities at risk. As an integrated approach, ASP builds on the interface of Disaster Risk Management (DRM), Climate Change Adaptation (CCA) and Social Protection (SP) to address interconnected risks, thereby overcoming the shortcomings of traditionally sectoral approaches.

The design of meaningful ASP measures needs to be informed by specific information on risk, risk drivers and impacts on communities at risk. In contrast, a limited understanding of risk and its drivers can potentially lead to maladaptation practices. Therefore, multidimensional risk assessments are vital for the successful implementation of ASP. Although many sectoral tools to assess risks exist, integrated risk assessment methods across sectors are still inadequate in the context of ASP, presenting an important research and implementation gap. ASP is now gaining international momentum, making the timely development of a comprehensive risk analytics tool even more important, including in Indonesia, where nationwide implementation of ASP is currently under way.

OBJECTIVE: To address this gap, this study explores the feasibility of a climate and disaster risk analytics tool for ASP (CADRAT-ASP), combining sectoral risk assessment in the context of ASP with a more comprehensive risk analytics approach. Risk analytics improve the understanding of risks by locating and quantifying the potential impacts of disasters. For example, the Economics of Climate Adaptation (ECA) framework quantifies probable current and expected future impacts of extreme events and determines the monetary cost and benefits of specific risk management and adaptation measures.

Using the ECA framework, this report examines the viability and practicality of applying a quantitative risk analytics approach for non-financial and non-tangible assets that were identified as central to ASP. This quantitative approach helps to identify cost-effective interventions to support risk-informed decision making for ASP. Therefore, we used Nusa Tenggara, Indonesia, as a case study, to identify potential entry points and examples for the further development and application of such an approach.

METHODS & RESULTS: The report presents an analysis of central risks and related impacts on communities in the context of ASP. In addition, central social protection dimensions (SPD) necessary for the successful implementation of ASP and respective data needs from a theoretical perspective are identified. The application of the quantitative ECA framework is tested for tropical storms in the context of ASP, providing an operational perspective on technical feasibility. Finally, recommendations on further research for the potential application of a suitable ASP risk analytics tool in Indonesia are proposed.

Results show that the ECA framework and its quantitative modelling platform CLIMADA successfully quantified the impact of tropical storms on four SPDs. These SPDs (income, access to health, access to education and mobility) were selected based on the results from the Hazard, Exposure and Vulnerability Assessment (HEVA) conducted to support the

development of an ASP roadmap for the Republic of Indonesia (Sett et al. 2022). The SPDs were modelled using remote sensing, gridded data and available global indices. The results illustrate the value of the outcome to inform decision making and a better allocation of resources to deliver ASP to the case study area.

RECOMMENDATIONS: This report highlights strong potential for the application of the ECA framework in the ASP context. The impact of extreme weather events on the four selected SPDs were successfully quantified. In addition, further developments of CADRAT-ASP can be envisaged to improve modelling results and uptake of this tool in ASP implementation. Recommendations are provided for four central themes: mainstreaming the CADRAT approach into ASP, data and information needs for the application of CADRAT-ASP, methodological advancements of the ECA framework to support ASP and use of CADRAT-ASP for improved resilience-building. Specific recommendations are given, including the integration of additional hazards, such as floods, droughts or heatwaves, for a more comprehensive outlook on potential risks. This would provide a broader overview and allow for multi-hazard risk planning. In addition, high-resolution local data and stakeholder involvement can increase both ownership and the relevance of SPDs. Further recommendations include the development of a database and the inclusion of climate and socioeconomic scenarios in analyses.

Ringkasan Eksekutif

Adaptive Social Protection atau Perlindungan Sosial Adaptif (PSA) merupakan suatu pendekatan untuk meningkatkan kesejahteraan masyarakat yang berpotensi mengalami risiko bencana. Sebagai pendekatan terpadu, PSA dibangun sebagai penghubung Manajemen Risiko Bencana (MRB), Adaptasi Perubahan Iklim (API) dan Perlindungan Sosial (PS) untuk mengatasi risiko yang saling terkait dengan membangun ketangguhan bencana, sehingga dapat mengatasi kekurangan pendekatan tradisional.

Rancangan langkah-langkah PSA perlu diinformasikan melalui informasi spesifik tentang risiko, pemicu risiko, dan dampak pada masyarakat yang terkena risiko. Sebaliknya, pemahaman yang terbatas tentang risiko dan pemicunya berpotensi mengarah pada praktik mal-adaptasi atau penyesuaian diri yang buruk. Oleh karena itu, penilaian risiko multidimensi sangat penting untuk keberhasilan penerapan PSA. Meskipun ada berbagai alat analisis untuk menilai risiko, metode penilaian risiko terintegrasi yang tersedia di berbagai sektor masih belum memadai dalam konteks PSA karena terdapat kesenjangan penelitian dan implementasi yang penting. Saat ini PSA mendapatkan momentum internasional yang mendorong pengembangan yang tepat dari alat analisis risiko yang komprehensif dan menjadi semakin penting, termasuk di Indonesia, di mana implementasi PSA secara nasional saat ini sedang berlangsung.

OBJEKTIF: Untuk mengatasi kesenjangan ini, studi ini mengeksplorasi kelayakan alat analisis risiko iklim dan bencana untuk PSA (CADRAT-ASP), menggabungkan penilaian risiko sektoral dalam konteks PSA dengan pendekatan analisis risiko yang lebih komprehensif. Analisis risiko meningkatkan pemahaman risiko dengan menempatkan dan mengukur potensi dampak bencana. Misalnya, kerangka kerja Ekonomi Adaptasi Iklim atau Economics of Climate Adaptation (ECA) menghitung kemungkinan dampak peristiwa ekstrem saat ini dan yang akan datang dengan menentukan biaya moneter dan manfaat dari manajemen risiko spesifik dan langkah-langkah adaptasi.

Dengan menggunakan kerangka kerja ECA, laporan ini mengkaji kelayakan dan kepraktisan penerapan pendekatan analitik risiko kuantitatif untuk aset non-keuangan dan aset tidak berwujud yang diidentifikasi sebagai pusat PSA. Pendekatan kuantitatif ini membantu mengidentifikasi intervensi hemat biaya untuk mendukung pengambilan keputusan berdasarkan informasi risiko untuk PSA. Oleh karena itu, studi ini menggunakan Nusa Tenggara, Indonesia, sebagai studi kasus untuk mengidentifikasi titik masuk potensial dan contoh untuk pengembangan lebih lanjut dalam penerapan pendekatan PSA.

METODE & HASIL: Laporan ini menyajikan analisis risiko sentral dan dampak terkait pada masyarakat dalam konteks PSA. Selain itu, laporan ini menyajikan dimensi perlindungan sosial atau Social Protection Dimensions (SPA) pusat yang diperlukan untuk keberhasilan pelaksanaan PSA dan identifikasi kebutuhan data masing-masing perspektif berdasarkan teori. Penerapan kerangka ECA kuantitatif diuji untuk badai tropis dalam konteks PSA dan memberikan perspektif operasional pada kelayakan teknis. Akhirnya, rekomendasi dapat mengusulkan penelitian lebih lanjut untuk aplikasi potensial dari alat analisis risiko PSA yang sesuai di Indonesia.

Hasil menunjukkan bahwa kerangka kerja ECA dan platform pemodelan kuantitatifnya, CLIMADA, berhasil mengukur dampak badai tropis pada empat SPD. SPD (pendapatan, akses kesehatan, akses pendidikan dan mobilitas) ini dipilih berdasarkan hasil Hazard, Exposure, and Vulnerability Assessment (HEVA) yang dilakukan untuk mendukung pengembangan peta jalan PSA untuk Republik Indonesia (Sett and others 2022). SPD dimodelkan menggunakan penginderaan jauh, data grid dan indeks global yang tersedia. Hasil ini menggambarkan nilai akhir untuk menginformasikan pengambilan keputusan dan alokasi sumber daya yang lebih baik untuk memberikan PSA ke wilayah studi kasus.

REKOMENDASI: Laporan ini menyoroti potensi yang kuat untuk penerapan kerangka kerja ECA dalam konteks PSA. Dampak peristiwa cuaca ekstrem pada empat dimensi perlindungan sosial, mulai dari akses ke perawatan kesehatan dan pendapatan hingga pendidikan dan mobilitas, berhasil diukur. Selain itu, pengembangan CADRAT-ASP lebih lanjut dapat dipertimbangkan untuk meningkatkan hasil pemodelan dan penggunaan alat ini dalam implementasi PSA. Rekomendasi diberikan untuk empat tema utama: pengarusutamaan pendekatan CADRAT ke dalam PSA, kebutuhan data dan informasi untuk penerapan CADRAT-ASP, kemajuan metodologi kerangka kerja ECA untuk mendukung PSA dan penggunaan CADRAT-ASP untuk pembangunan ketahanan yang lebih baik. Rekomendasi khusus diberikan, termasuk integrasi bahaya tambahan, seperti banjir, kekeringan atau gelombang panas, untuk pandangan yang lebih komprehensif tentang potensi risiko. Ini akan memberikan gambaran yang lebih luas dan memungkinkan perencanaan risiko multi-bahaya. Selain itu, data lokal beresolusi tinggi dan keterlibatan pemangku kepentingan dapat meningkatkan kepemilikan dan relevansi SPD. Rekomendasi lebih lanjut termasuk pengembangan database dan dimasukkannya skenario iklim dan sosial ekonomi dalam analisis.

1. Introduction

1.1 Problem statement and rationale of the study

In an increasingly interconnected world, risks induced by natural hazards as well as climate and socioeconomic changes are becoming more complex. These risks pose significant challenges to people, communities and governments to manage exacerbating threats (UNU-EHS 2021). National and local capacities to prepare for, respond to, and recover from disasters, adapt to climate change, and prevent livelihood shocks are often compromised through interconnected risks, leading to adverse impacts on communities, including poverty, food insecurity and other livelihood shocks (IPCC 2022).

Adaptive Social Protection (ASP) is an integrated solution at the interface of Disaster Risk Management (DRM), Climate Change Adaptation (CCA) and Social Protection (SP), aiming to address such interconnected risks by building resilience and promoting well-being for communities (Davies and others, 2009). ASP is about bundling efforts and resources from these three sectors to increase institutional collaboration, develop effective programmes and delivery systems, ensure adequate finance, and maximize data and information practices to support resilience building (Bowen and others 2020).

The provision of adequate data and information on risk is of particular importance for ASP as it establishes the groundwork for any intervention. The design of meaningful ASP measures needs to be informed by specific information on risk, risk drivers and impacts. This so-called "risk layering" (i.e. the design of interventions to address specific risks) helps to identify programmes and measures that are most effective in building resilience (Hallegatte and others, 2016). In contrast, a limited understanding of risk and its drivers can lead to negative outcomes and unintended side effects of well-intentioned interventions, both in the short and long terms (Eriksen and others, 2021). Therefore, multidimensional risk assessments are vital for the successful implementation of ASP. However, holistic approaches such as this have not yet been fully developed for this type of application.

Although many sectoral tools to assess risks are available, integrated risk assessment methods across sectors are still inadequate in the context of ASP, presenting an important research and implementation gap. To address this gap, this study explores the feasibility of a climate and disaster risk analytics tool for ASP (CADRAT-ASP) combining sectoral risk assessment approaches in the context of ASP with a more comprehensive risk analytics approach. Risk analytics improve the understanding of risks by locating and quantifying the potential impacts of disasters. For example, the Economics of Climate Adaptation (ECA) framework quantifies probable current and expected future impacts of extreme events and determines the monetary benefit of specific risk management

and adaptation measures (Souvignet and others, 2016). This quantitative approach helps to identify cost-effective interventions to support risk-informed decision-making for ASP.

The goal of this feasibility study is to examine the viability and practicality of applying a quantitative risk analytics approach, using the ECA framework, for non-financial and non-tangible assets that were identified as central to ASP. Therefore, it will not present a fully elaborated and applicable tool but instead identifies potential entry points and examples for the further development and application of such an approach. The analysis is conducted using Indonesia as a case study country, which will be further outlined in Chapter 3 (p.36).

The report begins with an introduction, outlining risk framing and a case study description that lays the groundwork for the study, followed by three main sections. Chapter 2 (p.19) presents an analysis of central assets in the context of ASP and respective data needs from a theoretical perspective based on literature. Chapter 3 (p.36) presents a proof of concept for the application of the ECA framework to non-financial impacts of extreme weather events in the context of ASP, providing an operational perspective on technical feasibility. Lastly, Chapter 4 (p.67) brings the preceding two chapters together by providing conclusions regarding feasibility and recommendations on further research needs for the potential application of a suitable ASP risk analytics tool in Indonesia, with the possibility of replication in a more global context.

1.2 Risk framing

Risk understandings may vary significantly among actors from different backgrounds. In order to assess risks and apply risk analytics, it is crucial to define and frame the term “risk” in order to provide a clear joint understanding on what it entails. This is particularly important for cross-sectoral settings such as ASP because terminology varies depending on the focus and mandates of a sector. Building on a previous risk assessment conducted in the context of ASP in Indonesia (Sett and others 2022), following international frameworks (cp. IPCC, 2012, see Figure 1, p.14), and elaborating on the ECA framework, risk is defined in this report as: "potential adverse impacts on communities resulting from hazards intersecting with exposure and vulnerability." **Hazards** are defined as potentially harmful events induced by natural processes and phenomena (World Bank, 2014), such as earthquakes, floods, tropical storms, winds and droughts. In the context of ASP, other hazards that are not purely based on natural processes also play an important role. For example, food insecurity results from the interplay of natural processes, such as droughts, with political, economic, social and cultural processes and conditions (Dewan Ketahanan Pangan and WFP, 2015), is considered an important hazard in the context of ASP (Sett and others 2022). However, these hazards are not a core focus of this particular study and will henceforth not be discussed in detail.

Hazards occur with a distinct intensity as well as frequency - sometimes referred to as a return period - in a given location.

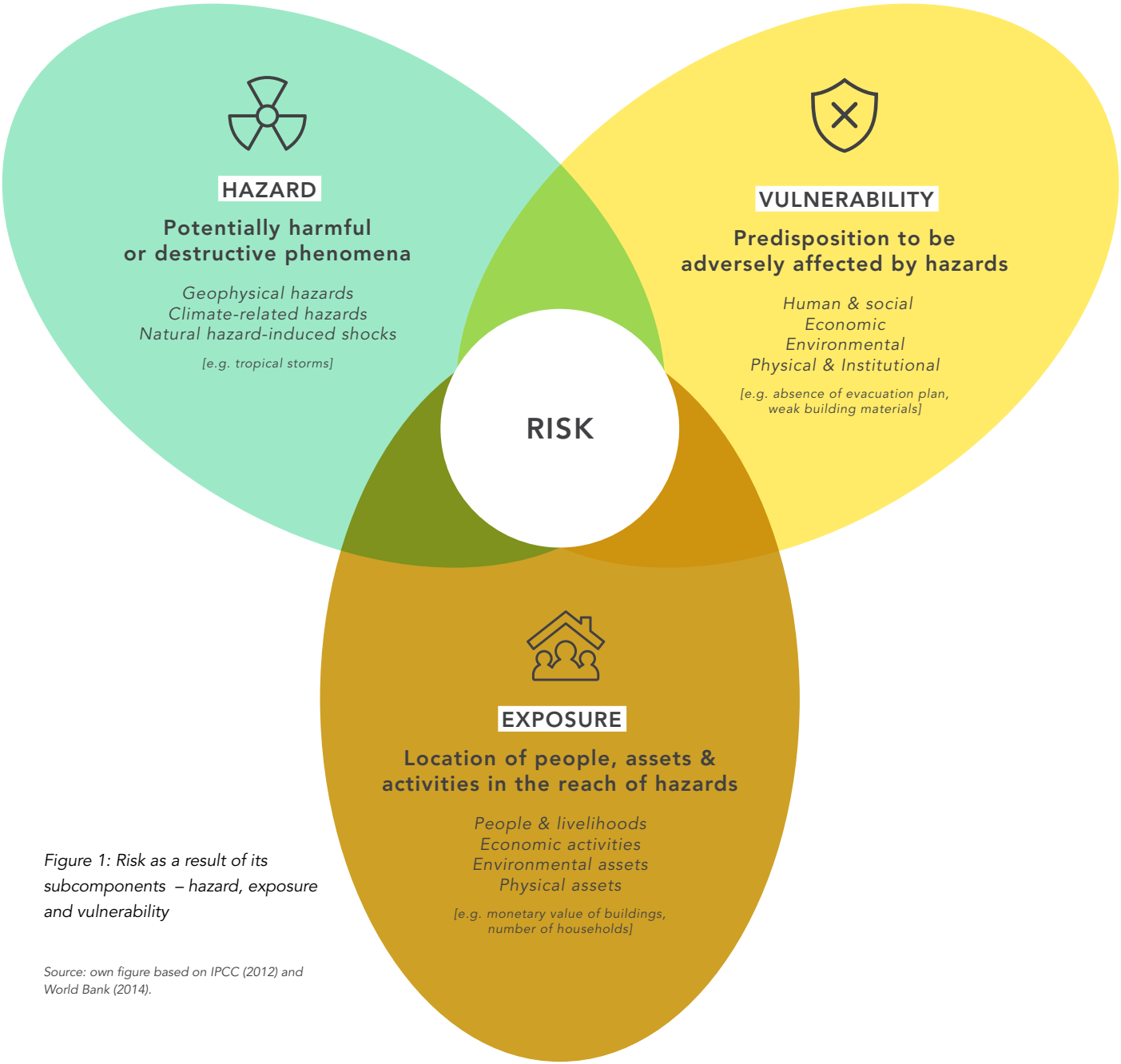

Figure 1: Risk as a result of its subcomponents – hazard, exposure and vulnerability

Source: own figure based on IPCC (2012) and World Bank (2014).

For example, an earthquake with a high magnitude might have occurred twice in the past 100 years and rainfall-induced floods with low to moderate inundation levels might have been observed annually in a specific location. Based on past hazard events and a developing understanding of climate change, future frequency and intensity of hazards can be estimated with some certainty. These future hazards can be expressed through probabilities, indicating how likely a certain hazard with a specified intensity is to occur in a given location and time frame.

Exposure is generally defined as the physical presence of someone or something in a location where a hazard might occur (IPCC, 2012). It is determined by deriving a complete inventory of all people, assets and activities in a potentially hazardous location. This comprises different population groups; physical, economic, institutional and environmental assets; and activities associated with government services and the livelihood of people. Such an inventory must consider the quantity (i.e. the number or amount of people, assets and activities in hazard zones) as the more people are located in hazard zones, the higher the exposure. Moreover exposure assessments must also consider the quality and value of assets and activities, as the higher a building's monetary value, the higher the exposure. This also comprises non-monetary values such as activities and services, which are vital for the context of ASP.

Finally, **vulnerability** is defined as the predisposition of exposed people, assets and activities to be adversely affected by a singular or multiple hazards (IPCC, 2012). The degree of vulnerability hence determines the levels of expected impacts of a given hazard on an exposed community. Vulnerability results from the interplay of intrinsic susceptibility to suffer harm with short-term (coping) and long-term (adaptive) capacities that could be used to avert or reduce harm (IPCC, 2012). For example, the damage from an earthquake to an exposed building will be higher if the building material is weak and thus more susceptible to the earthquake's forces. Furthermore, if the owner of the damaged building is not insured and does not possess savings to repair or rebuild the structure, this will further exacerbate the adverse impacts of this event on the affected individual, family and possibly community. As a result, high levels of vulnerability can severely impact human well-being.

1.3. CADRAT-ASP case study specification

To exemplify the feasibility of applying a quantitative risk analytics approach in the context of ASP, a case study approach was selected. This allowed for the analysis of a distinct geographic area and for one specific hazard. The deliberate focus of this study is presented as a first step in a comprehensive analysis. Thus, further research is needed to increase evidence and support a more detailed conceptual understanding.

Indonesia serves as the case study country for three main reasons. First, it can be considered a frontrunner in establishing a comprehensive ASP approach. The Government of Indonesia

has made ASP a policy priority to manage increasing risk and close protection gaps (Republik Indonesia, 2014). Moreover, it is working on a comprehensive strategy to implement ASP objectives (Bappenas, forthcoming). To support the implementation, it is crucial to develop devices such as risk analytics tools, making Indonesia a significant potential user of CADRAT-ASP. Secondly, Indonesia is characterized by high-risk levels overall, but with very different risk patterns, drivers and impacts across its regions and provinces (Sett and others 2022). This further supports the need for specific and policy relevant risk assessments and analytics. Thirdly, due to Indonesia's ongoing commitment to ASP development and high but differentiated risks, several studies in the context of ASP and risk assessments have already been conducted, providing vital data and information to support a proof of concept like the CADRAT-ASP analysis. As illustrated in Chapter 3 (p.36), the application of risk analytics is very data-intensive and thus dependent on the availability and quality of data for a case study location.

In order to assess the feasibility of applying the ECA framework for the case of ASP implementation in Indonesia and to further reduce complexity of the analysis, it was decided to focus on one single hazard for the case study. As it is important to select a natural hazard that is well established in the employed modelling tool, tropical storms were chosen. More specifically, this study focuses on the high wind speeds associated with tropical storms, whereas other aspects of the hazard – such as storm surges, heavy precipitation and subsequent floods – are not considered. Tropical storm winds and their respective damage have been a focus of various relevant modelling studies and are well established in the underlying modelling tool (Aznar-Siguan and Bresch, 2019). The ECA framework utilized for this study provides a high degree of reliability for the chosen hazard and allows for greater focus on the core objectives, such as identifying cost-effective interventions and providing support to fact-based risk decision-making for ASP.

As the most relevant case study region in Indonesia, Nusa Tenggara, comprising Nusa Tenggara Timur (NTT) and Nusa Tenggara Barat (NTB) provinces (see Figure 2, p.17), was chosen. These two provinces are characterized by the highest level of tropical storm hazards in Indonesia (UN OCHA, 2011; UNISDR, 2017), coupled with high exposure and vulnerability, making them a risk hotspot in Indonesia (Sett and others 2022). In addition, several comprehensive risk assessments have been conducted in this region (e.g. Boer and others, 2015) that provide valuable data and background information for this case study.

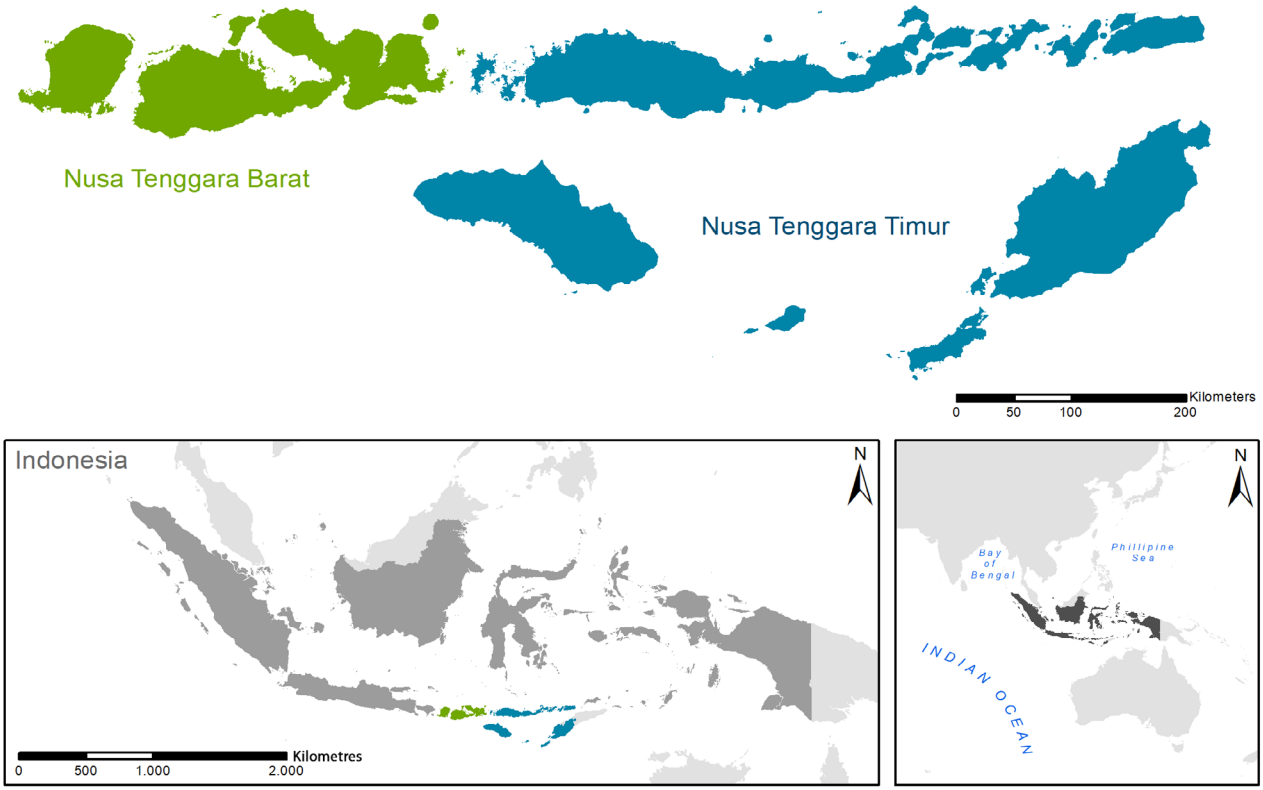

Figure 2: Location map of the case study region, Nusa Tenggara, in Indonesia

2. Data and information needs for risk assessments in the context of ASP

The following section provides insight into data needs for integrated risk assessments to inform the implementation of ASP approaches. Results are based on a literature review of risks, focussing on its subcomponents of exposure (Chapter 2.1, p.20) and vulnerability (Chapter 2.2, p.23), as well as their interplay, progressing to the impacts (Chapter 2.3) of tropical storms on the well-being of people and communities. While much of the analysis was focused on cases globally, applicable literature reflecting the Indonesian context was prioritized when possible. An overview of literature considered is provided in Table 1.

	EXPOSURE	VULNERABILITY	IMPACTS
International	Sudmeier-Rieux and others (2021); UNDRR (2021); Haavik (2020); Fekete (2019); Croppenstedt and others (2018); Stavro-poulou and others (2017); FAO (2015); BMI (2011); Carter and others (2019); O'Brien and others (2018).	Zhang and Liang (2021); Wisner (2006); Liu and others (2020); Marin-Monroy and others (2020); Lenzen and others (2019); Bartlett (2008); Cutter and Finch (2008); McGuire and others (2007); Thomalla (2006); Schwartz and others (2011); UNESCO (2018); Al-Samarrai (2013); Gough (2021); Rodriguez (2020); Papathoma-Köhle and Thaler (2018); Uriarte and others (2019); Grace and others (2015); Khanduri and Morrow (2003).	Lin and others (2020); OECD (2020); Kutikuppala (2019); Mitsova (2018); Lindenmayer, and Noss (2006); Pincock (2005)
		Niacsu and others (2019); WHO (2019); Rakotobe and others (2016); ADB (2016); Gardiner and others (2016); Xi (2015); Doocy and others (2013); Burnham and Hooper (2012); Keim (2008)	
	BEH and RUB-IFHV (2021); Sett and others (2021); Neise and others (2021); GIZ and others (2018); GIZ (2014)		
Indonesia	(Sett and others 2022); Bappenas (2021a); Republic of Indonesia (2021); Wahyuni and Wiati (2021); Bappenas (2019); ILO (2019); TNP2K (2018)		GPFI (2017); Tohari and others (2017); Schmitt and others (2014); ADB (2012); ADB (2006)

Table 1: Overview of literature reviewed to identify exposure factors, vulnerability factors and intermediate impacts

2.1. Exposure

Exposure is central to ASP as it is closely linked to resilience building, which is a core objective of ASP. The identification of exposed people, assets and activities helps to determine who and what is at risk, and in turn who and what should be targeted in resilience-building interventions. To ensure inclusive resilience building, it is vital to consider multiple exposure factors, covering different dimensions. To capture this broad range of factors, literature on exposure, resilience and protection targets has been reviewed (see Table 1, p.19). As a result, multiple exposure factors have been identified that are relevant for ASP. They have been divided broadly into five categories (see Figure 3, p. 21), which further divides categories by factors):

- Population
- Economic assets and activities
- Environmental assets and services
- Critical infrastructure and basic services
- Public and civil assets, services and institutions

In reality, there is significant overlap between these categories and there is often no clear differentiation. In addition, the boundaries are not always fully clear, e.g. environmental assets are sometimes considered as components of economic activities, and public services might be considered a critical infrastructure, depending on the official classification within a country. Nevertheless, this distinction was chosen as it depicts key exposure categories relevant to ASP provision. In order to sustainably reduce exposure, comprehensive approaches ranging across categories are needed.

First and foremost, the exposure of the population living in the reach of hazards must be identified to inform well-designed ASP interventions. On the one hand, it is important to assess the exposure of the entire population to derive a broad understanding of overall protection needs. This is of particular importance for ASP, which aims at addressing risks to covariate shocks (i.e. disruptions that affect a large part of the population at once) (O'Brien and others, 2018). As outlined in Chapter 1 (p.12), such widespread adverse impacts tend to exceed capacities of sectoral approaches and thus present an important entry point for ASP. Therefore, it is crucial to identify the share of the overall population exposed to hazards that could potentially manifest in covariate shocks.

On the other hand, every population is heterogeneous and composed of people that might be very different based on distinct conditions, as will be further outlined in Chapter 2.2. (p.23). Therefore, protection needs vary significantly across populations (Carter and others, 2019). To address these distinct needs, it is vital to consider the exposure of specific people and population sub-groups and not just look at an entire population. For example, it is crucial to identify the exposure of disabled people as they might require specific support in response to occurring shocks. Thus, it is crucial to identify who is exposed to best support ASP interventions.

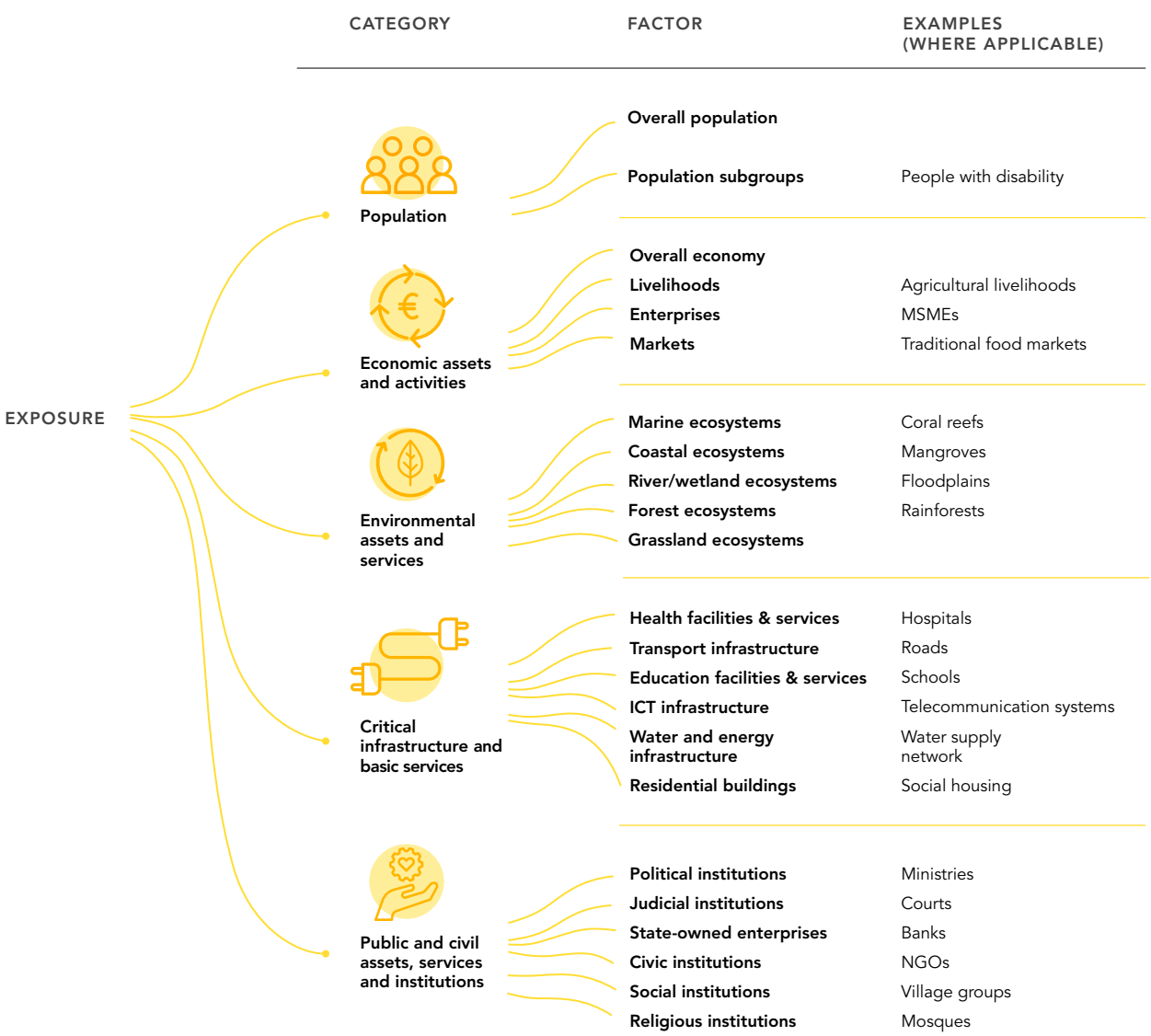

Figure 3: Exposure categories

Second, the exposure of economic assets and activities is vital in the context of ASP. The disruption of economic activities and the damage to economic assets induced by hazard events often prevent people from securing necessities for their lives, evoking an urgent need for assistance (FAO, 2015). In this study, economic activities and assets are composed of livelihoods, comprising all activities for securing people's necessities; enterprises, which provide a significant share of livelihood opportunities; and markets, which are important for the realization of livelihoods. Similarly to the exposure of population, it does not only matter how many activities and assets are located in hazard prone areas but also what kinds of livelihoods, enterprises and markets are there. It is therefore important to assess the exposure of the overall economy as well as the exposure of specific activities and assets.

For example, it is important to identify if livelihoods in the informal employment sector are exposed as those often fall outside the protection of formal safety nets and hence require additional consideration (Stavropoulou and others, 2017). This is particularly evident amongst those engaged in agricultural livelihoods which is of particular relevance in South-East Asia (ILO, 2015). Similarly, the exposure of micro-, small- and medium-sized enterprises (MSMEs), including related activities and jobs, is detrimental to food security and well-being (Croppenstedt and others, 2018; Stavropoulou and others, 2017). Although MSMEs are usually not characterized by high monetary values compared to large companies, they employ a significant share of the working-age population in Indonesia and are thus of high value as many livelihoods depend on them (Neise and others, 2019; ILO, 2019).

Third, environmental assets like forests or wetlands, and larger ecosystems like marine, river, or coastal systems were identified as important because they provide crucial services for communities linked to ASP. As ecosystems and their services can be disturbed by hazard events, their protection is also important to ensure continued access and support for communities (Sudmeier-Rieux and others, 2021). For example, tropical storms often damage trees, which in turn leads to a depletion of forest assets and services, including the provision of protection against natural hazards such as landslides and tsunamis. In addition, ecosystems significantly contribute to people's well-being, e.g. in food of water provision (UNDRR, 2021). Thus, without well-functioning ecosystems, additional assistance would be required to provide these and other crucial services for communities (Wahyuni and Wiati, 2021).

As a fourth category, exposed critical infrastructure and basic services need to be identified to support ASP interventions. Critical infrastructure, such as hospitals, roads, schools, and telecommunication systems, are central to the delivery of ASP benefits. For example, roads damaged or blocked after a storm may prevent the timely delivery of assistance to affected communities. In line with the other exposure categories, it is necessary to identify not only the quantity and type of critical infrastructure in hazard zones but also the services that are linked to physical assets. For instance, hospitals need to be considered not only based on the monetary value of the buildings and equipment within them but also on the non-monetary value of health and emergency service provision. Beyond the physical assets, critical services also need to be considered as they immediately affect the population in terms of access to drinking water, sanitation, health and education services (Haavik, 2020).

The last exposure category comprises public and civil assets, services, and institutions. This category consists of governmental institutions, including political institutions, law

enforcing judicial institutions, and state-owned enterprises, as well as non-governmental organizations, including civic, social and religious groups. Apart from the primary role of state organizations in planning and implementing ASP, civil actors also play an important role. On the one hand, non-state institutions such as traditional markets, food kiosks, and online delivery businesses partnered with state-owned banks and post offices to deliver SP benefits, such as food assistance, to eligible households (TNP2K, 2018; Annur, 2020). On the other hand, social and religious institutions maintain well-established informal SP schemes in Indonesia, such as in-kind assistance according to needs. Furthermore, they have a strong potential to enhance preparedness through awareness raising, training and early warning communication, which can significantly contribute to resilience building for communities. Therefore, it is important to assess the level of exposure of these institutions to identify potential risks of interruption of their services to communities induced by a hazard event, which could have severe impacts on people's well-being.

2.2. Vulnerability

As previously indicated in Chapter 2.1 (p.20), vulnerability is another main component of ASP as it determines the severity of the impacts of hazards on the people, assets and activities that are exposed. Vulnerability demonstrates the need for protection and assistance and presents itself in multiple ways. The different vulnerability factors identified in the literature review can be broadly divided into five vulnerability categories (see Figure 4 (p.24), which also divides categories into factors):

- Human and social susceptibility and capacities
- Economic susceptibility and capacities
- Environmental susceptibility
- Physical susceptibility
- Institutional susceptibility and capacities

Although these categories align closely with those of exposure, there is no exclusive link between the respective exposure and vulnerability categories. For example, economic susceptibility and capacities do not only affect economic assets and activities but also link to population and institutions. As a result, most vulnerability factors are not specifically related to a singular exposure factor but instead relate to many. In addition, different vulnerability factors are often interconnected and might reinforce each other (UNU-EHS, 2021).

First, the identification and reduction of human and social vulnerability is the central objective at the core of ASP. Main intrinsic factors that increase human susceptibility and thus increase the likelihood to suffer harm from hazardous events include age (Bartlett, 2008), health condition (Schwartz and others, 2011) and disability (McGuire and others, 2007). For example, poor health conditions can increase the susceptibility of a person to physical suffering, thus increasing their likelihood to be severely injured in a hazardous event

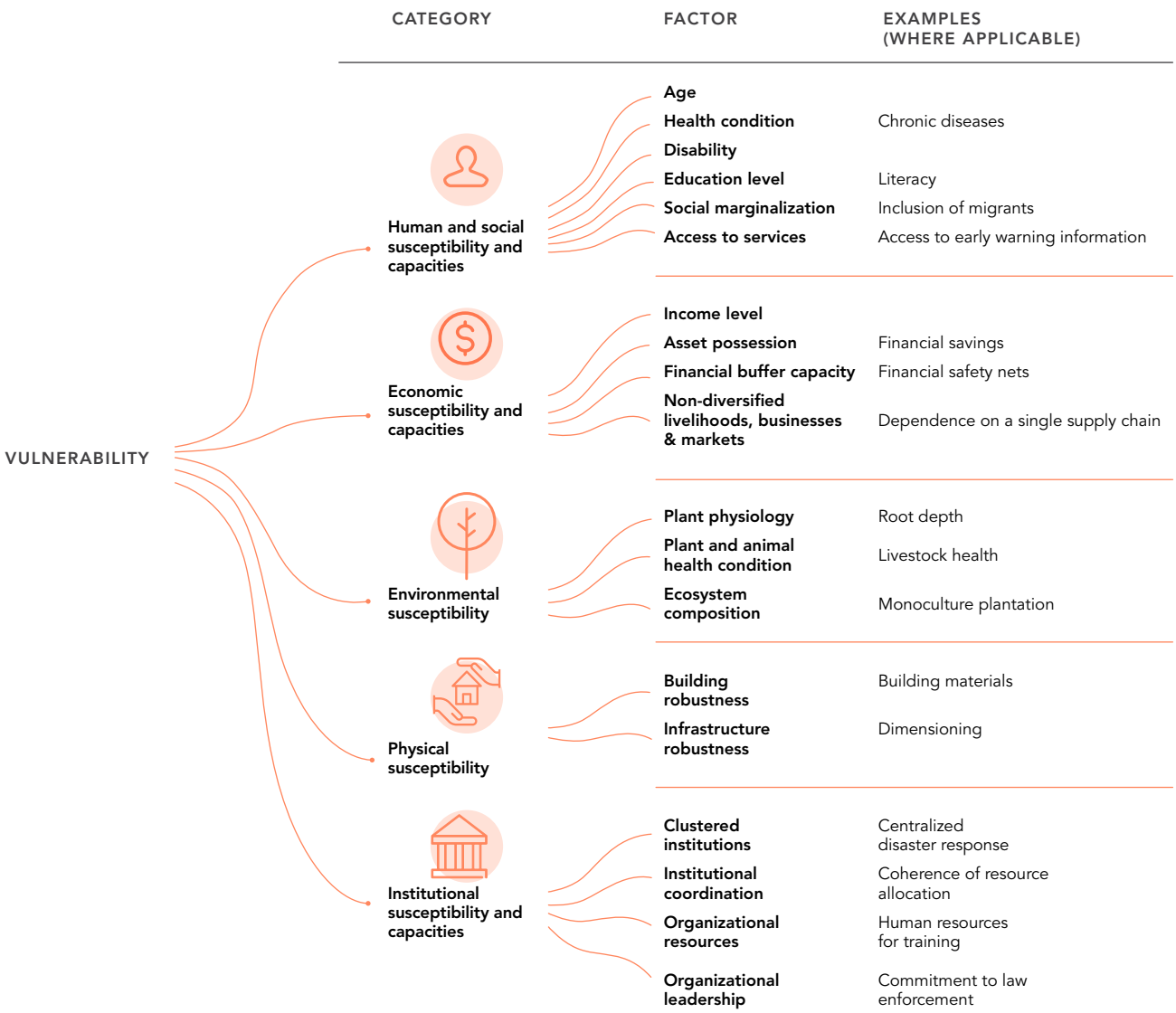

Figure 4: Vulnerability categories

(Schwartz and others, 2011), such as a tropical storm, evoking an urgent need for assistance.

In addition, these susceptibility factors can also have a significant effect on human and social capacities to cope with and adapt to risk. Age, health condition and disability, among other factors, have great influence on people's well-being, including education and employment opportunities. For example, literacy is an important factor that supports coping and adaptation as it enables one to access information that can help prepare for, respond to and recover from hazard events (Wisner, 2006). Access to education and other basic services is hence crucial to building resilience. However, this access is often hampered by people's (mental) health conditions. Indonesia is characterized by one of the largest gaps worldwide for school attendance of children with and without disabilities, leading to significantly lower education and literacy levels for those living with disabilities (UNESCO, 2018). In addition, lack of coping and adaptive capacities can also be linked to social marginalization and the exclusion of specific social, cultural or religious groups from basic service provision or participation in public life (Thomalla and others, 2006). These circumstances are often experienced by migrant groups, placing them with further disadvantages and leaving them particularly vulnerable (Cutter and Finch, 2008).

Economic vulnerability was identified as vital in the context of ASP as financial capital is so closely linked to resilience-building activities. Income is considered as one of the main determinants of vulnerability because it has a significant impact on many other vulnerability factors, including access to services, information and education (Gough, 2021; Rodriguez, 2020). This could also be observed for Indonesia, where school attendance was found to be much lower for children of lower income households (Al-Samarrai, 2013). Income can support households' financial buffer capacity and thus provides an important opportunity to prepare for, respond to and recover from shocks. If financial means are unavailable to a household, they are likely to implement unsustainable coping strategies, such as the selling of livestock or reducing nutrition consumption, which may provide short-term relief but ultimately increase vulnerability in the long term. This also applies to enterprises, particularly MSMEs, which often lack formal safety nets in Indonesia and are thus vulnerable to the effects of shocks (ADB, 2016). In addition, economic susceptibility can be evoked by centralized, non-diversified livelihoods, businesses and markets. If a national or regional economy is too dependent on a single sector, such as tourism, it becomes fragile and increasingly susceptible to the effects of a shock. Similarly, if a household is solely dependent on agricultural activities, it is very susceptible to shocks if harvesting practices are affected by a hazard.

Additionally, environmental susceptibility must be considered in ASP interventions to ensure long-term and sustainable resilience-building. Fragility of ecosystems can lead to significant damage and disruptions of the goods and services that they provide. For example, the physiology of trees that manifest in shallow root systems reduces their capacity to withstand strong gusts and can in turn be aggravated by poor environmental health conditions (Uriarte and others, 2019). Environmental quality and protection are hence important factors to reduce vulnerability. Similarly, specific livestock species have been identified as more sensitive to climate change impacts and more likely to be affected by hazards when their health condition is poor (Grace and others, 2015).

Physical susceptibility is another important designation in the ASP dialogue. The type and quality of building materials used determine the robustness of buildings and infrastructure and thus affect the people, assets and activities linked to these

buildings. For example, buildings made of cardboard and plywood are more susceptible to strong winds during a tropical storm compared to buildings made of concrete because of a heightened fragility (Khanduri and Morrow, 2003). Similarly, road networks, communication systems and water supply systems need to be durable to avoid damage and disruption in the event of a hazard. For example, if strong winds damage or destroy a bridge, this is likely to cause significant adverse effects on people and activities, hindering the accessibility of important services and disrupting supply chains.

Lastly, institutional vulnerability presents a central risk factor in the context of ASP. As already outlined in Chapter 2.2 (p. 23), civil actors and public institutions provide essential services to communities. If these actors and institutions face high susceptibility and lack capacities, a stark depletion of the services they provide is likely during a hazard event. Institutions can be susceptible if they are geographically or structurally clustered without important redundancy systems in place (Papathoma-Köhle and Thaler, 2018). For example, if response activities are organized and executed by one central institution, it poses the risk that response will be hampered once the institution is affected. Therefore, robust and redundant systems are necessary to build resilience. In addition, government institutions play a key role in capacity-building for communities. Training, awareness building and disaster risk education play major roles in protecting people and livelihoods. If the training resources and capacities of institutions are limited, this could severely reduce coping and adaptive abilities.

2.3. Impacts

To identify expected impacts of the previously outlined risk components an impact chain approach was applied. This additionally serves to illustrate possible causalities, which are an important pre-step to understand cascading impacts and develop targeted ASP. After a methodological introduction to the impact chain approach, specific impacts linked to tropical storm risk in Indonesia will be outlined. More specifically, they will be considered using the example of post offices and state-owned banks and services as exposed elements that are also central to the successful delivery of ASP benefits in Indonesia.

2.3.1. Impact chain methodology

Impact chains help demonstrate possible outcomes that may result from the interaction of various risk drivers by understanding the causal relationships of relevant hazards, exposure, and vulnerability factors (GIZ and others, 2018). Impact chains typically begin with a hazard event including specific climate signals. They are a very useful approach to show how these signals affect exposed people, assets and activities, as well as how affectedness is influenced because of specific vulnerabilities. Due to its focus on ASP, this study extends the assessment of impacts by not only looking at primary and secondary intermediate impacts but also assessing impacts on human well-being, which is a central objective of ASP, in general and in Indonesia (Bappenas, 2021b). Well-being is conceptualized based on the OECD framework, which distinguishes 11 well-being categories, such as income and wealth, housing, health and social connections (OECD, 2020). Such an impact chain shows the progression of hazard interacting with exposure and vulnerability, leading to intermediate impacts and finally impacts on well-being, as seen in Figure 5. It is worth noting that the figure shows a simplified linear progression from one element to the next. In reality, there are multiple interlinkages and feedback loops within and across the risk and impact subcomponents (see Chapter 2.3.2, p.30).

In order to reduce the complexity of the multiple risk factors identified in the preceding chapters and their diverse impacts, and to thereby better identify and understand causality, this study selected a variety of exposure factors to be assessed in greater detail. For each of the exposure categories outlined in Chapter 2.1 (p.20), one specific exposure factor was selected and assessed (see Table 2, p.29). Chapter 2.3.2 (p.30) will outline the results of the impact chain for one of these exposure factors: public and civil assets, services, and institutions. Results drawn from the impact chains of the other exposure factors will be integrated into this discussion where feasible as a comprehensive overview of all potential impacts and their drivers would exceed the scope of this study. The subsequent results discussion should be considered as proof of concept.

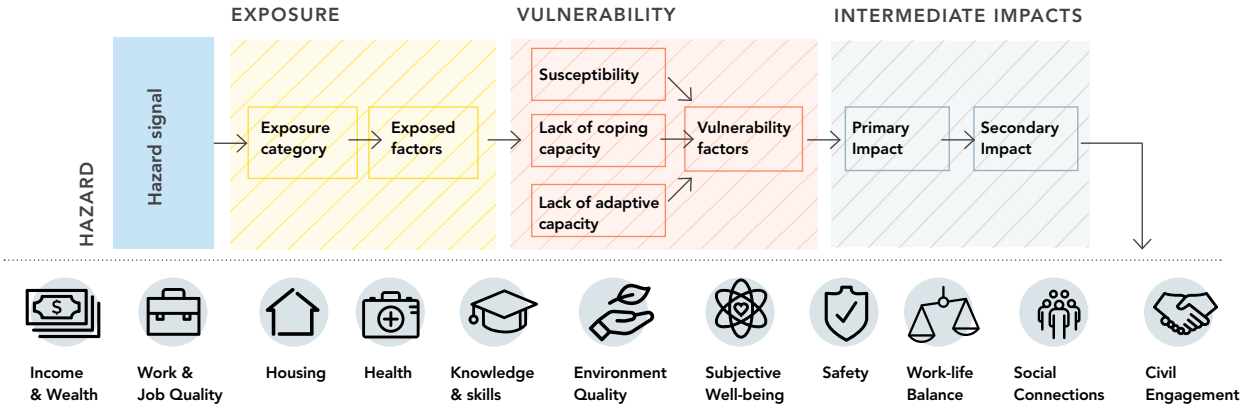

Figure 5: Impact chain approach of this study

EXPOSURE CATEGORY	EXPOSED FACTOR SELECTED FOR IMPACT CHAIN ANALYSIS	RELEVANCE OF SELECTED FACTOR FOR ASP IN INDONESIA
Population	Informal workers	Highly vulnerable group that comprises a significant share of the overall working-age population
Economic assets and activities	Agricultural livelihoods	Livelihood that is highly vulnerable to climate change and natural hazards but that is also highly relevant for many household incomes, the overall economy and food security
Environmental assets and services	Forest ecosystems	Provide important ecosystem services while facing severe degradation, including due to deforestation
Critical infrastructure and basic services	Health-care facilities and services	Provide vital services that support health as one of the central protection goals of the Indonesian government; of fundamental importance during and after disaster events
Public and civil assets, services and institutions	Post offices / state-owned banks and services	Key role in supporting the delivery of social protection benefits

The coloured category will be analysed in detail in the following chapter.

Table 2: Selected exposure factors for the impact chain analysis and their relevance for ASP in Indonesia

2.3.2. Impact chain for exposed post offices and state-owned banks and services

Ensuring that benefits reach those in need in a timely and effective manner is of paramount importance to ASP. Hence, it is key to know about exposure, vulnerabilities and impacts resulting from a hazard event, such as a tropical storm, on institutions assigned with this task.

Indonesia's post offices, which are organized under the state-owned PT Pos Indonesia (Persero), have a history of operating as federal assistance outposts by acting as distribution hubs supporting the delivery of social protection benefits, including cash transfers, as well as sharing information about and assisting enrolment in social protection programmes (World Bank, 2017).

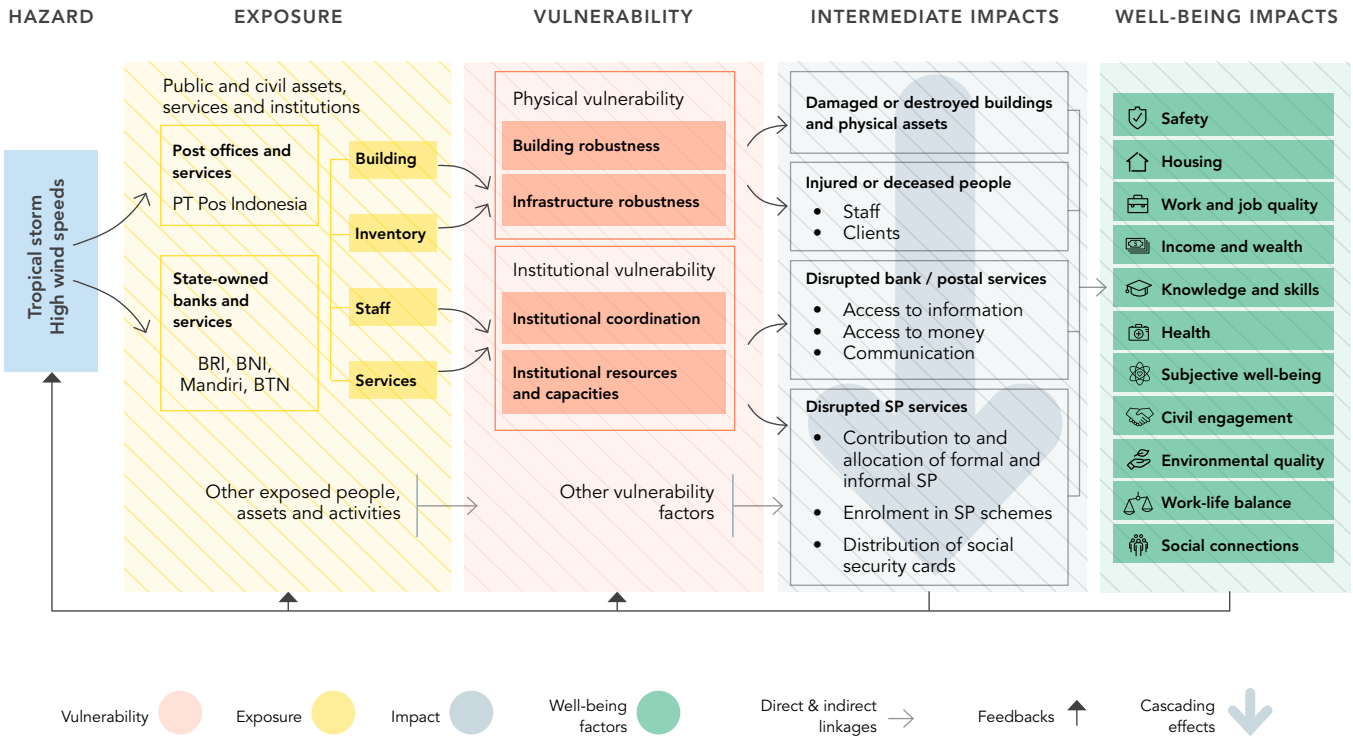

Figure 6: Impact chain for the risk of tropical storm winds on post offices/ state-owned banks and services. Straight lines illustrate direct links.

Starting in 2017, state-owned banks took on the responsibility for the transfer of SP funds to recipients on the local level (TNP2K, 2018).

To ensure the continuation of services during and after a disaster such as a tropical storm, it is important to identify potential effects and impacts on the institutions supporting SP delivery, information and enrolment, as well as to pinpoint potential secondary impacts linked to the disruption of services they provide (see Figure 6, p.30). Hence, the following chapter outlines impacts of disruptions of post office and state-owned bank operations, the effect of interruptions on their actual functions as well as on services relevant for (A)SP, and ultimate consequences for well-being.

Exposure

To comprehensively assess potential impacts of tropical storms on post offices and state-owned banks and their services, it is important to consider exposed buildings or elements of buildings and their operations. In addition, it is vital to include their staff and additional physical assets, such as inventory (see Figure 6, p.30). Finally, services like financial transactions of banks, mail services of PT Pos and the management and allocation of SP benefits by the institution in charge also need to be assessed. These elements are closely interlinked, as all of them are necessary for the successful execution of service operations.

The exposure assessment of these four elements varies significantly, adding additional complexity to the process. The exposure of buildings is the most straightforward, as the fixed location of a facility can be identified and geolocated, pinpointing its exact spatial location within a geographic area. This information can then be used within a Geographic Information System (GIS) to identify if the facility is located within an area prone to a certain hazard, in this example a tropical storm. For other fixed physical inventories and services located within the premises, a similar methodology applies.

However, several assets, such as vehicles used to deliver mail to households, are not fixed to a specific physical location and therefore cannot be geolocated. The same applies for staff members and mobile equipment, which after working hours or during the provision of services may be dispersed throughout the serviced area making its presence uncertain. Determining whether or not assets are present in an exposed area provides a degree of accuracy to the modelling tool utilized for this study. Accordingly, the inability to track and geolocate mobile assets presents a major challenge for exposure assessment.

Furthermore, several exposed elements of post offices and state-owned banks and their services are closely linked to other exposure categories (as highlighted in the "exposure box" of Figure 6, p.30). As indicated, the staff of these institutions also need to be considered as part of the population when assessing risks and impacts. For instance, they could be exposed in their residential houses. Similarly, the services provided by these institutions are integrally linked to economic assets and activities and critical infrastructures. This applies for both online services, due to dependence on energy and Information and Communication Technology (ICT) networks for providing own online services such as the delivery of SP benefits, and offline services, e.g. due to their dependence on road networks for the distribution of mail. It is hence vital to consider these linkages when assessing risks and potential impacts.

Vulnerability and impacts

Several vulnerability factors were identified that can either be directly linked to the identified exposed elements or indirectly linked to related exposure factors, which in turn impact the services that post offices and state-owned banks provide — in this case, the distribution of SP benefits (see the "vulnerability box" in Figure 6, p.30).

First, tropical storms can damage or even destroy physical assets, particularly buildings and inventory. In addition to wind speeds, the expected damage of buildings and other physical assets is determined by building and material fragility as well as a lack of maintenance, and hence a combination of physical susceptibility and a lack of institutional capacity. In addition, damage can also occur from trees that can't withstand strong storms and fall onto buildings and assets. Therefore, the damage is also indirectly linked to exposure and vulnerability of ecosystem assets and services, e.g. due to improper environmental management (Gardiner and others, 2016; Xi, 2015; Liu and others, 2012). Damaged or destroyed physical assets will likely result in secondary impacts on people, basic services, economies and governments.

For example, damage to or destruction of post offices and banks can lead to physical harm, including injuries or even fatalities of staff, further impeding operability and ultimately SP services. Consequently, staff and other people in or near such impacted buildings who are harmed or even killed by the event are directly linked to other exposure categories, showing interlinkages and cascading impacts. For instance, in the case of affected health-care staff or buildings, it could lead to shortages which sequentially limit essential emergency medical services (Keim, 2018; Mitsova and others, 2018; WHO, 2019).

During recovery, any damage to or destruction of buildings and inventory will require repair or reconstruction, which necessitates resources, particularly financial means and labour, something in short supply following a disaster event. Often, however, limited financial means or conflicting interests of (local) government authorities might leave important sectors aside or with too few finances. This could potentially even lead to negative effects on SP allocation when local governments face a high financial burden due to a significant number of damaged or destroyed state-facilities leading to a redistribution of social assistance to reconstruction.

Apart from damaged physical assets and injured people, the third major impact on post offices and state-owned banks is the disruption of their services. As mentioned before, such disruption can be induced by the damaged building itself, damaged inventory or external infrastructure – most notably, energy, ICT and transportation networks – and injured staff members. The disruption of services is hence also linked to multiple vulnerability factors, such as institutional susceptibility and a lack of capacity. Expected impacts are higher if services are organized as centralized systems that do not contain meaningful backup processes, for example if there is only one post office in a certain region without a plan to substitute services in case of emergency. This lack of redundancy is likely to cause more severe and longer service disruptions. In the case of the aforementioned damaged external infrastructure such as a damaged power grid, cascading effects for all electricity-dependent systems in the area can be expected, including on post offices and banks. In general, it is important to develop and implement emergency plans that at least provide temporary solutions. However, this requires institutional capacities, which, when lacking, may even increase the expected duration of disrupted services.

The disruption of post office and state-owned bank operations in Indonesia would seriously affect services linked to SP delivery, which in turn can adversely affect each of the dimensions of well-being (see "impact boxes" in Figure 6, p.30). First and foremost, the allocation of SP benefits depends on the continuation of services of the distributing institution, such as post offices and banks. Major SP programmes, including the Family Hope Programme (PKH), the Smart Indonesian Programme (PIP), the Collective Working Group (KUBE) and the Elderly Social Assistance Programme (ASLUT), require program beneficiaries to collect payments. Until 2017, this happened at their local PT Pos Indonesia office (ADB, 2006; ADB, 2012; Schmitt and others, 2014; World Bank, 2017); since 2017, they are required to open an account in a state-owned bank (TNP2K, 2018). For isolated communities

and regions that don't have the infrastructure to support digitized forms of social assistance there are some exceptions that still depend on PT Pos Indonesia for cash delivery (TNP2K, 2018).

In addition, informal SP benefits, such as the delivery of remittances through postal delivery services, can also be disrupted, thus further reducing the accessibility of this type of assistance (GPFI, 2017). Many households depend on the receipt of this type of assistance to secure their basic needs, and the number of dependent households is likely to increase in the aftermath of severe tropical storms. However, if post office or state-owned bank operations and in turn SP benefit allocation is disrupted, households in need of assistance may consider alternative ways of securing their basic needs. As mentioned in Chapter 2.2 (p.23), this can lead to the application of negative coping strategies, such as selling livestock or taking children out of school to work, in order to create additional income that can help to satisfy the most urgent needs (Mathers and Slater, 2014). These actions can, however, have serious adverse consequences on well-being in the midterm to long term, especially on work and job quality, income and wealth, knowledge and skills, health, and subjective well-being.

In addition to delayed allocation of SP to households already enrolled in formal SP programmes, the disruption of post office or state-owned bank operations can also impede the registration and subsequent allocation of benefits to households that are in need of assistance but not yet enrolled in any programme. As normally distributing institutions such as post offices and banks are involved in supporting the enrolment of households in programmes including the process of creating social security cards (KKS), which are required to receive benefits, disruptions would significantly reduce opportunities for non-registered households to receive assistance (Tohari and others, 2017; Schmitt and others, 2014). Ultimately, this could have similar impacts on well-being.

Lastly, the disruption of mail delivery and banking services can also lead to adverse impacts on well-being caused by a reduction in communication activities or access to money, e.g. for building materials to repair destructed residential buildings. Despite many mail services being displaced by electronic mail and messaging providers, PT Pos Indonesia is often the only choice for those living in areas designated as 3T, which refers to the most rural and outermost parts of the country (46% of total PT Pos network coverage) (PT Pos Indonesia, 2018). If this communication is disrupted, so too will be delivery of postal, financial and logistical services. Ultimately, that can reduce opportunities for civil engagement and social connections (PT Pos Indonesia, 2018).

Similarly to the outlined risks and potential impacts of tropical storms on post offices and state-owned banks and their services, comparable risks and impacts can be observed for other exposure factors. For example, high physical susceptibility and a lack of maintenance of critical infrastructures, such as hospitals, ICT, transportation systems, and water and electricity supply, can lead to a disruption of basic services. By leaving households without access to essential goods like water, food, energy and health care, many aspects of well-being are adversely affected. Hence, it is important to not only consider direct impacts but also understand less apparent indirect and cascading linkages and risks that could be detrimental to lives and livelihoods.

2.4. Summary of main results on risk and impacts

Previous chapters have illustrated the magnitude of risk and potential impacts that are linked to tropical storms, generally and in Indonesia. In this context, three main observations were derived from the impact chain analyses of risk and associated impacts.

First, risks in the context of ASP are highly interconnected and result from the interplay of multiple factors. For example, the exposure of services is linked to the exposure of buildings, infrastructure, people, the environment and institutions. Even if services might not be directly exposed, the physical infrastructure, such as buildings and equipment, they depend on can be. Services can also be disrupted through exposed staff in charge of service delivery, or via damaged energy, ICT and road networks. In addition, risks can be exacerbated by vulnerability factors that are not directly linked to the exposed elements. For instance, post office or bank services can be very vulnerable to the effects of tropical storms due to a lack of capacity within national or local government agencies to plan and prepare for extreme events or to reduce the susceptibility of infrastructure and people.

Second, a single hazard can trigger multiple impacts due to cascading effects and thereby induce greater effects on communities' well-being. As illustrated in Figure 6 (p.30), tropical storms can lead to severe impacts on infrastructure and services, including road closures, loss of power supply, loss of communication and structural damage. These impacts often cascade to secondary impacts, such as the disruption of postal, financial and health-care services, which are essential for the delivery of SP benefits, ultimately harming those in greatest need of assistance. Therefore, a disruption to the road network resulting from a storm can have wide-ranging effects on people's health, food security and income.

Finally, impacts can have significant feedback effects on risk factors, mainly on vulnerability and exposure. For example, a disruption of energy supply might lead to an increased use of fuelwood for cooking and heating. Similarly, a disruption of income might force people to exploit natural resources and sell firewood or other environmental goods. This will lead to increased deforestation and hence environmental degradation, which can subsequently act as a driver of risk and exacerbate communities' exposure and vulnerability.

3. Quantifying climate impacts on social protection dimensions: a proof of concept

3.1. Framing climate risk analytics for the ASP context

Different approaches have taken up the task of examining social protection landscapes more closely to inform adaptation strategies and response plans. However, quantification and spatial analysis of potential non-financial impacts of disastrous events are often lacking. To better understand these impacts, a detailed analysis of individual components and dimensions is required.

In this light, we identified the Economics of Climate Adaptation (ECA) framework as an appropriate tool to test the feasibility of an adaptive social protection module that estimates, in quantitative terms, the expected impacts of extreme events on key social protection dimensions. First, this is because ECA is an open-source tool that has been applied in several case studies during the past decade and has been supported by a large community of experts. Secondly, because it has shown a high level of flexibility regarding the scale of its implementation (i.e. national, regional and local) as well as for different types of contexts and hazards.

ECA is a decision-making support framework integrating stakeholder engagement and climate vulnerability and risk assessments with economic impact studies to quantify probable future damage and to determine an optimal adaptation portfolio for various climate risks. For a probabilistic analysis the ECA framework relies on the quantitative modelling platform CLIMADA, an open-source modular and collaborative platform, primarily focusing on quantifying current and future economic impacts of climate change. CLIMADA conducts benefit-cost analyses of potential adaptation measures reducing future damage.

Estimating probable damage to non-physical and non-financial assets, such as those of interest for ASP, entails an expansion of the scope of ECA. To do so we have selected a set of Social Protection Dimensions (SPDs), such as access to health and access to education, instead of physical assets, as focal points of our analysis. Notwithstanding, the modelling platform CLIMADA requires several inputs, including 1) a probabilistic set of hazards (probable intensity and frequency of hazards within the study area), 2) the location and quantification (e.g. monetary) of the assets or SPDs of interest, and 3) a definition of the relationship between the impact on the SPDs and the intensity of hazard set (i.e. vulnerability functions).

Figure 7 (p.37) provides an overview of the ECA framework, including the described inputs for CLIMADA and the decision-

making support outcomes ECA offers for adaptation and risk management. The figure highlights the innovative risk analytics module that the proof of concept in this study is exploring within an ASP context. The non-financial analysis is key to quantify and locate probable impacts of disastrous events beyond monetary losses and is the focus of this report. However, the financial analysis of potential damage typically estimated by an ECA study is also recommended for ASP as it informs the need for resources, the options for investments and the gaps in risk coverage that can be later transferred using tools such as insurance.

The proof of concept in this study showcases how CLIMADA and the ECA framework can be used to estimate the expected

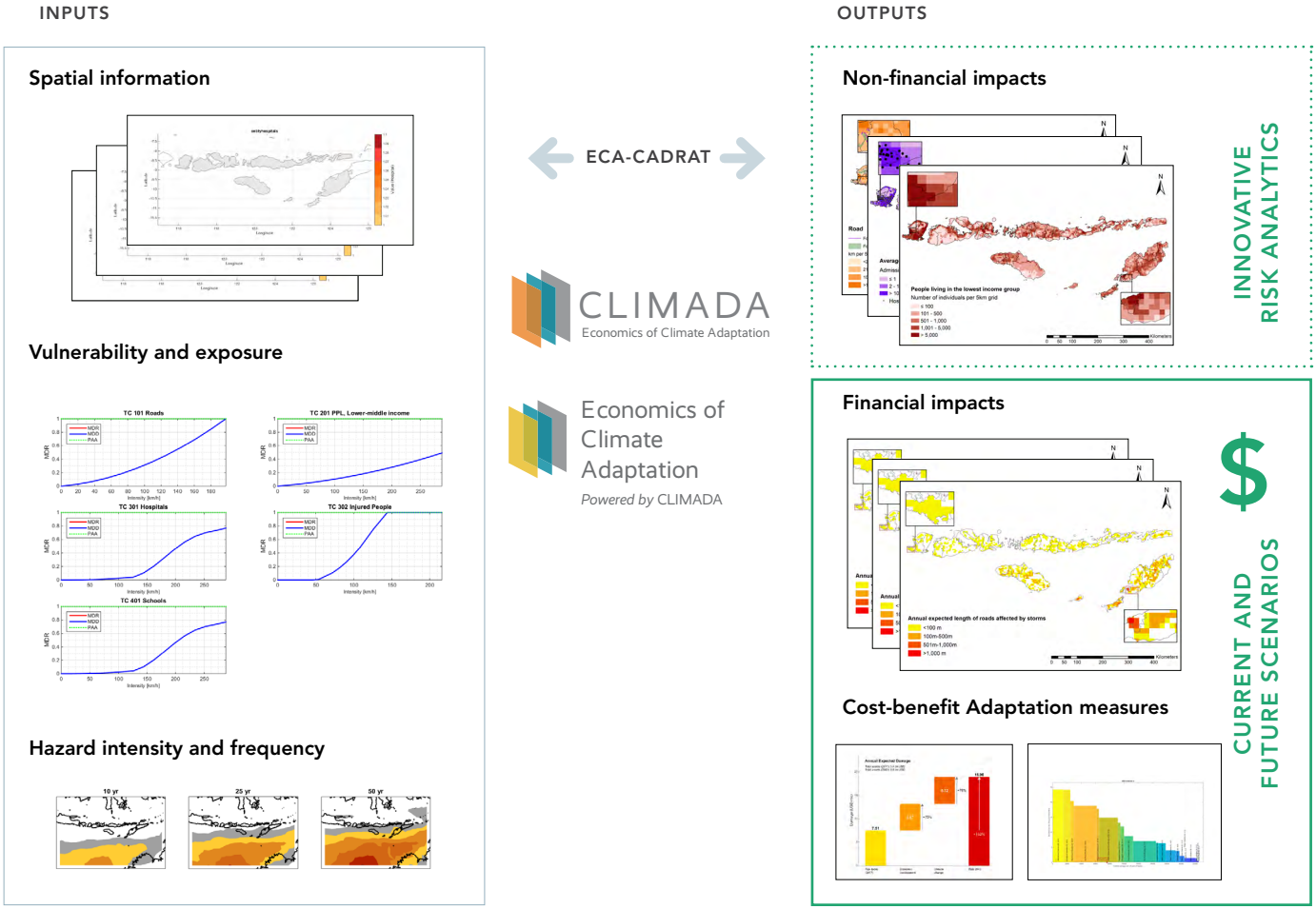

Figure 7: Overview of the ECA framework with inputs and outputs for CLIMADA

impacts on and damage to selected SPDs within the social protection and well-being landscapes in the Republic of Indonesia, specifically in the Nusa Tenggara region, where impacts of high-speed winds and tropical storms, in general, can be expected.

The following sections describe in further detail the set of SPDs analysed, the theoretical and methodological frameworks implemented, and the possible applications for decision-making in the context of adaptive social protection. Lessons learned and next steps are suggested for each SPD, and preliminary results from CLIMADA are presented for illustrative purposes.

3.2. Quantifying exposure and vulnerability: social protection dimensions

As introduced in the previous section, CLIMADA requires three main sets of inputs: 1) The selection of a natural hazard, which in this study is tropical storms and is modelled internally by a module in CLIMADA; 2) The physical locations and some related values representing the quality or status of the selected SPDs; and 3) The relationship between the intensity of the hazard and the potential impact over the given value of each SPD.

In terms of physical location, the SPDs can be understood as access to given services, e.g. health services and transportation systems, and for the most part these can be conveniently linked to physical infrastructure or facilities (road networks, hospitals, etc.). The values assigned to the SPDs are derived from quantitative indicators that measure certain aspects of the dimension, e.g. available beds in hospitals or kilometres of built roads in a certain area. These data sets enable CLIMADA to estimate the exposure of the SPDs in different locations and to present the geodistribution of the expected impacts over the assessed infrastructure, rather than generalizing the impacts of the disastrous events over the whole research area.

ECA and CLIMADA quantify vulnerability using damage curves. Also known as vulnerability functions or damage functions, they describe the relationship between the hazard intensity, in the case of tropical storms here expressed in wind speed, and the mean damage degree of the respective group of assets. Typically, damage curves are drawn from scientific literature and calibrated using local historical damage and impact data, as well as expert opinions. However, for non-physical assets, there is scarce research available, and even less with Indonesia as the target region. The damage curves used for this study are therefore reconstructions from a compilation of literature, and the results presented should only be considered as proof of concept for the use of ECA on SPDs and shall not be used directly for decision-making.

Considering the goal of this proof of concept and based on the results of the Hazard, Exposure and Vulnerability Assessment (HEVA) conducted in the context of ASP in Indonesia (Sett and others 2022), a small but diverse set of social protection dimensions, or intangible assets, was selected. Figure 8 (p.39) presents these dimensions, the

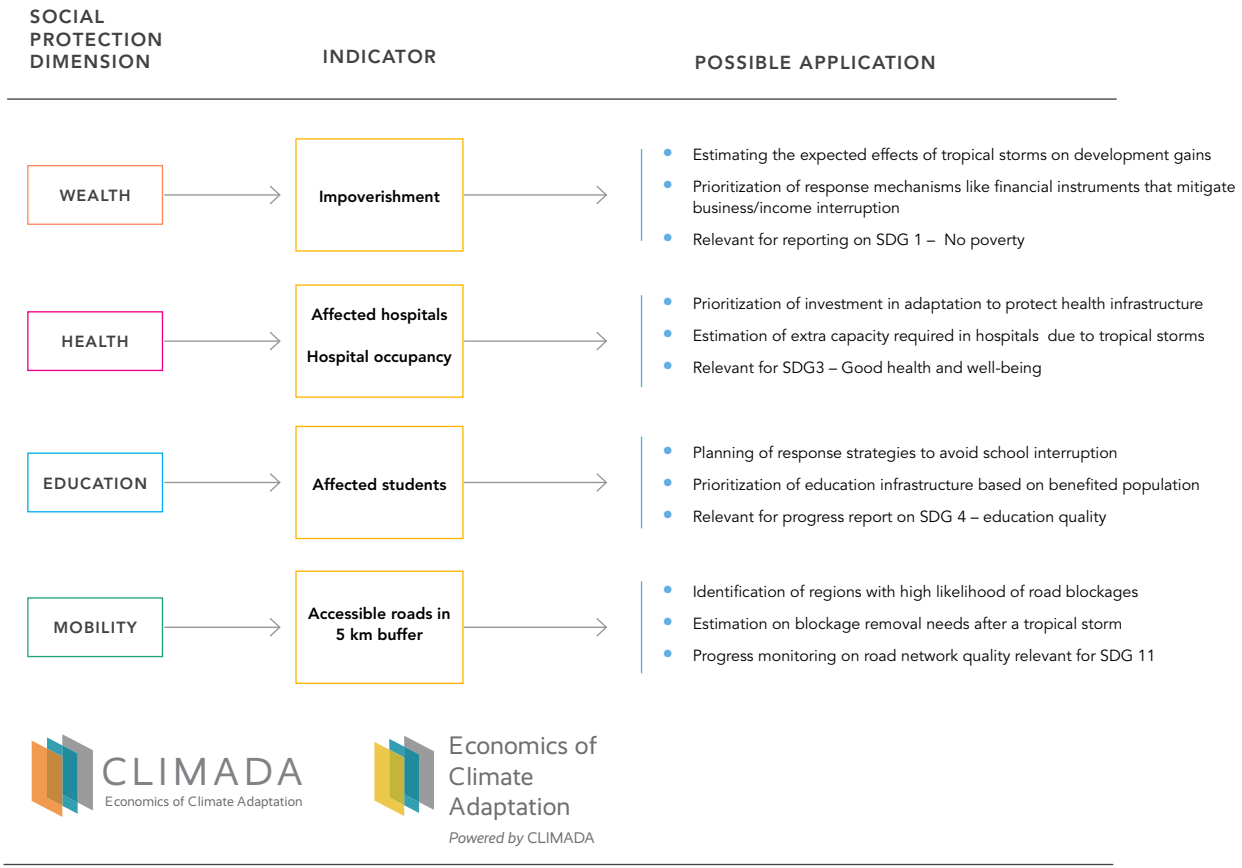

Figure 8: Selected social protection dimensions (non-tangible assets) for this proof of concept

related indicator to be quantified and possible applications of the expected results for decision-making.[1]

In the following sections, we explain in more detail each SPD, its relevance for ASP, the theoretical framework behind the choices of intangible, physical and non-physical assets, as well as what data were used. The results segment illustrates

1 Time and data limitations in effect limited the opportunities to thoroughly assess and validate the damage curves applied here, which largely rely on literature review. A higher level of stakeholder engagement for verification and access to subnational damage and loss data would certainly improve the confidence level and preciseness of the results significantly. However, the applied damage curves serve as a reasonable proof that the methodology is suitable to assess non-tangible assets.

the impact of strong winds on these various assets in terms of expected annual damage. We conclude each SPD by providing a further outlook on the possible application for local policy in Indonesia and highlighting the next steps that we consider could further improve the quality of the results presented.

3.2.1. Impact on Income

Relevance for ASP

Income reduction was chosen as an indicator of the impact of tropical storms on wealth as a core dimension of resilience and adaptive capacity. Changes in income are to be expected in the aftermath of a disaster. They reduce the resilience and adaptive capacities of different social groups, but especially those already on the edge of poverty.

The relationship between disaster risk and impoverishment is bidirectional (UNISDR, 2009). Disasters aggravate the depth and breadth of poverty with possible effects over time, while increasing poverty makes the impacts of disasters much more severe (Dartanto, 2017; UNISDR, 2009). People in poverty are more vulnerable to disasters because they are more likely to live in hazardous areas and are less able to invest in risk reduction measures. Besides, lack of social protection forces impoverished people to use their limited assets to face disaster losses, which can push them into further poverty (Shepherd and others, 2013).

Different weather-related disasters impact impoverishment to different extents; the findings of this SPD can help to gauge the extent to which tropical storms increase the depth and breadth of poverty. This information could be useful to guide the development of social protection programs focusing, for example, on helping impoverished people to buffer disaster losses. Such efforts will translate in benefits on poverty relief and therefore contribute to meeting Sustainable Development Goal (SDG) 1.

Once impacts on different income groups are spatially distributed, decision makers can take proactive action in terms of measures to reduce exposures, prepare for early and targeted response action in case of a disaster and establish (social) safety net systems bolstering people's adaptive capacity.

Theoretical Framework

Disasters, including tropical storms, can contribute to the impoverishment of people in several ways. They can exacerbate loss of income due to death or injury of household providers; damage or destruction of assets and housing can depress consumption and expenditure; and damage to roads and infrastructure can limit access to employment and goods markets (Rush IV, 2014). However, the magnitude of such losses remains unknown because they are not easy to determine (Anttila-Hughes and Hsiang, 2013); therefore, quantifying the extent to which these impacts exacerbate impoverishment is increasingly important to reduce vulnerability and to design effective disaster risk management policies.

According to Baez and others (2017), empirical research on the effects of weather-related disasters on impoverishment has focused on examining several variables linked to household welfare, such as consumption, asset ownership, income, mortality and investment in health, education and nutrition. Among them, for tropical storms in particular, the most studied socioeconomic dependent variables are related to consumption (Anttila-Hughes and Hsiang, 2013; Henry and others, 2020; Skoufias and others, 2020) and income (Baez and others, 2017; Ishizawa and Miranda, 2019).

All the studies evaluated employ, as a source of socioeconomic data, household-level surveys, which allow access to more disaggregated information. For instance, Ishizawa and Miranda (2019) analysed the impact of tropical storms on the poor in Central America using total per capita income and per capita labour income as dependent variables. To identify the impact of the storms on the different sources of income of Filipino households, Anttila-Hughes and Hsiang (2013) considered, in addition to total income, agricultural wages, non-agricultural wages and entrepreneurial income.

For consumption, besides per capita consumption, several studies analysed the effects on household welfare of different types of consumption expenditure, such as expenditure on food, non-food, protein, fruit, cereal, fuel, education, medical- and personal care and travel/communication among others (Anttila-Hughes and Hsiang, 2013; Henry and others, 2020; Skoufias and others, 2020). Moreover, some of the studies assessed the impacts on different groups of the population, such as households below and above the poverty threshold (Baez and others, 2017) or urban and non-urban households (Anttila-Hughes and Hsiang, 2013).

Regarding hazard data, two main differences can be noticed in the measurement of tropical storm destruction (Henry and others, 2020). On one hand, there are studies that used storm incidence or wind speed categories, such as Baez and others (2017), which evaluated the impacts of Tropical Storm Agatha on household well-being in Guatemala through standardized precipitation anomalies recorded from weather stations. And on the other, more recent studies (Anttila-Hughes and Hsiang, 2013; Henry and others, 2020; Ishizawa and Miranda, 2019) applied physical wind field models to modelled local damage (Henry and others, 2020).

Regarding the wind speed threshold to cause damage, the majority of the studies set the lower boundary at 119 km/h (lower boundary of a category 1 hurricane according to the Saffir-Simpsons scale) (Henry and others, 2020; Skoufias and others, 2020). Moreover, Skoufias and others (2020), in their analysis to identify vulnerability to poverty in the Philippines, set two different assumptions regarding damage caused by wind speed: 1.) 98 km/h is the wind speed above which damage occurs and 2.) 203 km/h is the wind speed at which half the property value is lost.

INCOME LEVELS			
LOWEST	**LOW**	**MEDIUM**	**HIGH**
% of people living below 1,005 US$/year	% of people living between 1,005 and 3,975 US$/year	% of people living between 3,976 and 12,275 US$/year	% of people living above 12,276 US$/year specifically related to employment

Table 3: Four income classes

Source: adapted from de Bono and Chatenoux (2015, p. 7)

Data and Methodology

The relationship between "changes in income" and tropical storms has been addressed in very few studies to date. As a consequence, no data has been collected with this specific target in mind. Henceforth, a new and possibly innovative approach was developed specifically for this proof of concept. In our case, we aim at quantifying and localizing how many people can be expected to fall below a certain income threshold due to tropical storms in Nusa Tenggara Barat and Nusa Tenggara Timur.

Spatially distributed data from the Global Exposure database for GAR 2015 (GEG-2015), an open exposure global data set that integrates gridded socioeconomic indicators about population, capital stock, income, employment, health and education (de Bono and Chatenoux, 2015) are drawn from.[2] The data provided by GEG-2015 are georeferenced at a 5x5 km resolution and provide the share of each grid point's population in the respective income group. Specifically for income, the GEG-2015 developed a group of indicators which includes the resident population subdivided into four classes based on income per capita (de Bono and Chatenoux, 2015) (Table 3).

In this study, we focus on the LOW-income group and how the income of this population group is affected by tropical storms as a reduction in their annual income could potentially push them into poverty[3] (i.e. the LOWEST income group) (see Figure 9 (p.43) for the number of people living in the lowest income group). The relationship between expected income reduction and the intensity of a tropical storm is based on findings of Anttila-Hughes and others (2013) and was calibrated using

2 The GAR Global Exposure database was intentionally chosen, as it comprises several indicators at a reasonable scale for almost all countries globally, and thus ensures comparability to other studies. The database underlying the 2015 GAR was used, as data of recent GAR versions (i.e. 2017 and 2019) was not accessible to the authors. Although the use of more recent data of at least similar quality would have generated more accurate estimates, the use of the GAR 2015 data is considered sufficient to establish the feasibility of the approach in this report.

3 The value of US$1,005 per year was used as a threshold for low-income economies by the World Bank in 2010. It is equivalent to a daily value of US$2.75, and incomes above this are closely correlated with significant increases in non-monetary measures of quality of life, such as life expectancy at birth, mortality rates of children and enrolment rates in schools.

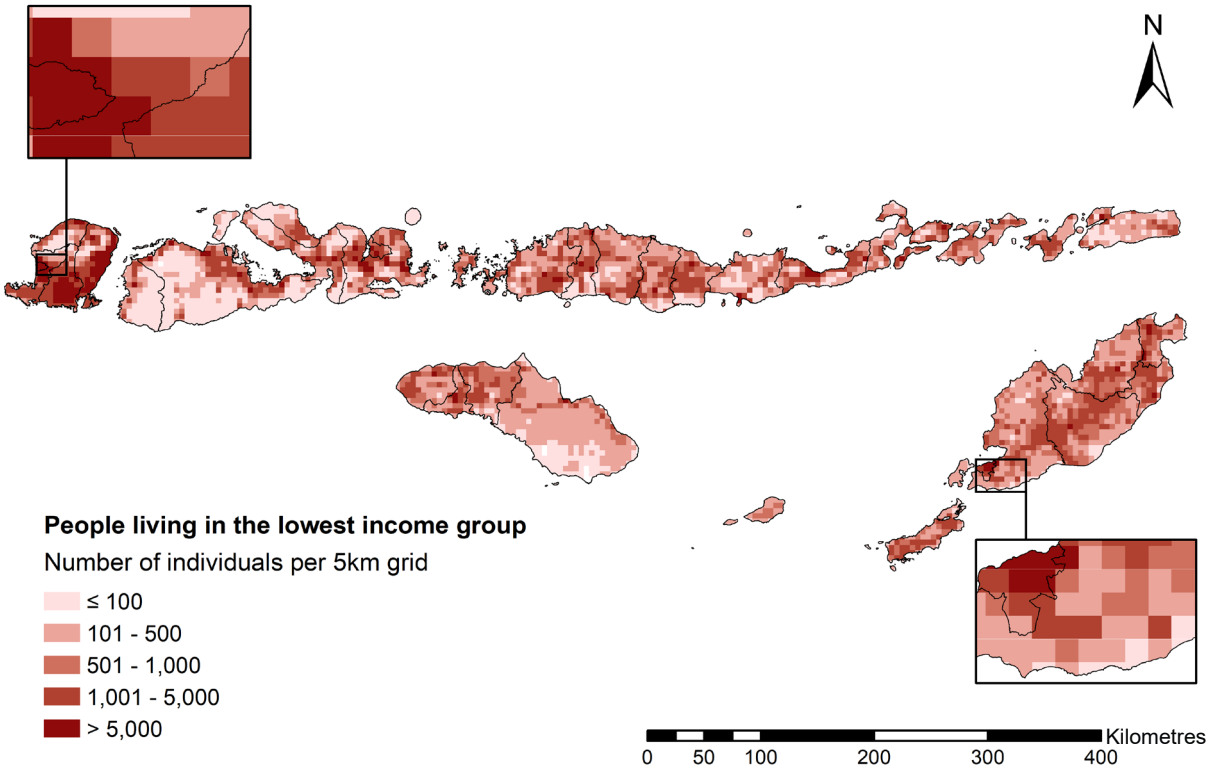

Figure 9: Number of people living in the lowest income group. Shades of red indicate the number of people living at the lowest income level (below US$1,005 a year) in the respective 5x5km grid.

Data source: de Bono and Chatenoux (2015).

local poverty data on the district level from 2002 to 2020 to better reflect the local context.[4]

Results

In this section, we describe the outcome of CLIMADA using the SPD described above. A probabilistic set of tropical storms based on the behaviour of regional historical events was calculated. They were incorporated in the model to see where impacts are likely to be stronger over a large period of time. In regions where the maximal wind speed is highest, damage – in our case, the number of people falling into the lowest income level – are likely to be highest. The model connects the location of individuals with the intensity of wind speeds and calculates the resulting damage. Hence, depending on their location, individuals with the same income level can be

4 Data are drawn from BPS-Statistics Indonesia, National Socioeconomic Survey, and accessible at https://ntt.bps.go.id/indicator/23/35/1/number-of-poor-populatian-by-regency-municipality.html (Nusa Tenggara Timur) and https://ntb.bps.go.id/indicator/23/225/1/number-of-poor-people-by-regency-municipality.html (Nusa Tenggara Barat).

impacted differently. Figure 10 shows the annual expected damage of tropical storms to people in terms of loss of income. In every 5x5km grid, the number of people falling into the lowest level of income is highlighted. The Timor and Sumba regions are the worst affected due to their larger exposure to stronger wind speed. Nonetheless, urban areas in the Lombok and Sumbawa isles show a strong impoverishment rate. In urban areas, this is most likely linked to the already high number of people living at low-income levels with few savings and low resilience to negative change.

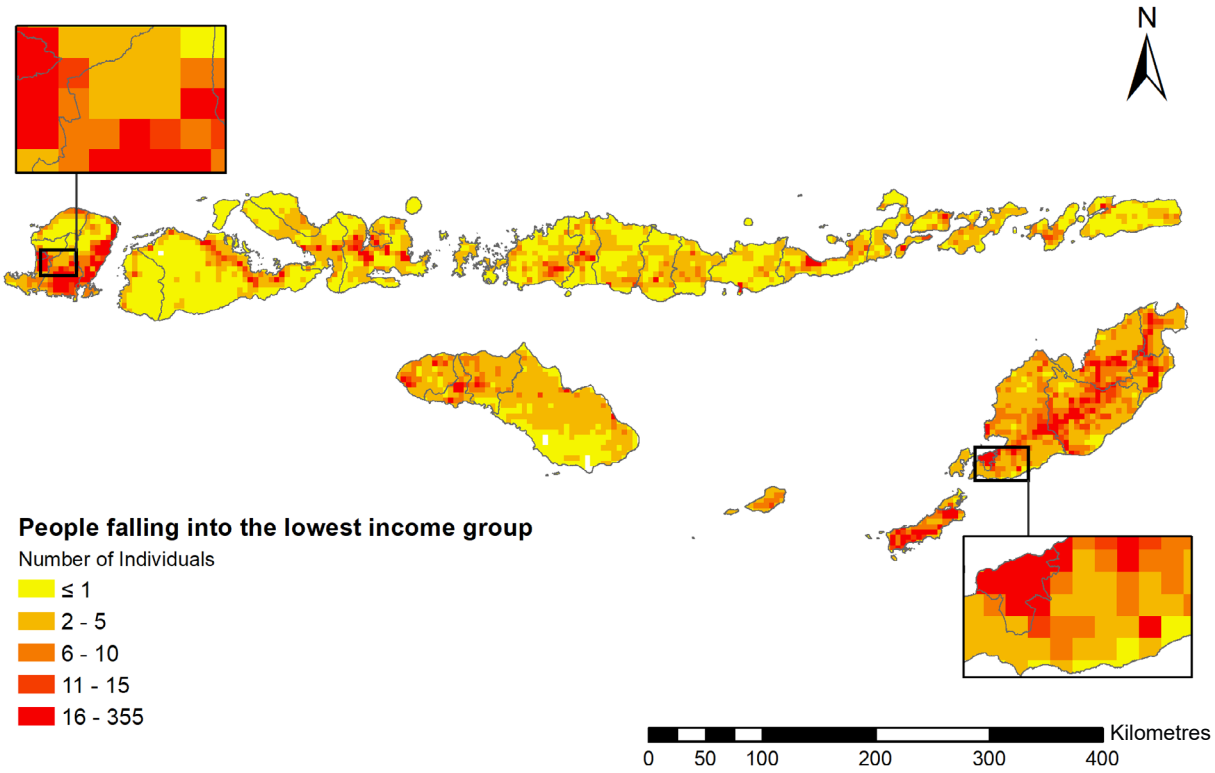

Figure 10: Impact on Income – Impoverishment: Shades of yellow and red indicate the expected number of people falling in the lowest income level (below US$1,005 a year) due to tropical storms at a 5x5km grid level

Outlook: possible applications for policy

Higher poverty levels are often observed in the aftermath of disastrous events. Yet, measuring the extent of such an increase is challenging. Whereas extended interruptions in economic activities caused by the destruction of key infrastructure straightforwardly lead to losses in GDP, direct damage to housing and losses from the informal economy are much harder to quantify. As discussed above in the theoretical framework, estimations of impacts on households and small-scale livelihoods rely mainly on aftershock surveys, which require time and financial resources that are scarce during emergency situations.

With appropriate estimations of the magnitude and location of the expected increase in population living in poverty conditions due to income reduction, policymakers and decision makers can design solutions to be triggered by the occurrence of extreme events that provide timely support for families to get back on their feet. Similarly, governments can use the information provided as a baseline to prioritize investments in further research on those areas with higher potential of impoverishment linked to extreme events and to better understand local livelihoods and invest in improving the resilience of their income-generating activities.

Local authorities can, for example, use the identified locations where there is high exposure to hazards and/or large numbers of people with incomes close to the poverty line to consider incorporating in poverty relief programs a risk component to protect the hard-earned gains from extreme events.

To illustrate the potential applicability of our results, we have identified three specific regulations in Indonesia whose implementation could benefit from estimations of income reduction. The following cash transfer programs aim at providing economic assistance to victims of disasters, ensuring the sustainability of their livelihoods after a disastrous event.

1. Law of Republic Indonesia No. 24 of 2007 on Disaster Aid Financing and Management:

   a. Article 60, The Government and Regional governments shall jointly bear responsibility for disaster management funds

   b. Article 69, Disaster victims who have lost their livelihood can obtain soft loans for productive business

2. Regulation of National Disaster Management Agency No. 3 of 2013 concerning The Management of Refugees in the Emergency Situation - Article 22, Compensation and Refund for Refugees:

   a. Providing wages for those who are employed

   b. Providing compensation

   c. Restoration of residence and political status

   d. Socialization of compensation and refunds for refugee rights

   e. Providing assistance in lost documents

   f. Providing aid for home improvement stimulus funds

   g. Providing assistance for replacing plant seeds and cattle

   h. Providing assistance for house and land rental costs

   i. Monitoring and the compensation process and return of rights

3. Regulation of Social Ministry No. 1 of 2013 concerning Social Assistance for Disaster Victims:

   a. Article 17, providing economic recovery assistance for communities especially related to the small and medium-sized enterprises (SMEs) in the form of cash transfers.

Additionally, impacts on income can also inform reporting on international platforms, like progress on SDG 1: No poverty. In particular for target 1.5: Build resilience to environmental, economic and social disasters. But also relevant for the sustainability of target 1. b: Establishment of poverty eradication policy frameworks at all levels.

Next steps

This section reviews the potential of CLIMADA and ECA to quantify the impact of disasters on intangible assets such as loss of income. Over the course of the literature review and conceptualizing our approach, we collected several other ideas to expand the approach to quantify impacts on income and poverty in a meaningful way.

The first opportunity for expansion is to include further income groups to get a better overview of the dynamics of the whole population rather than just a certain part of it; for this, a very similar approach to the one implemented in this study could be repeated for other income groups. Additionally, or alternatively, to analyse general shifts between income groups a specific focus on different levels of poverty, e.g. transitory poverty versus extreme poverty, could be placed. For that, indicators such as the poverty gap index (P1) or the poverty severity index (P2) can be used.[5]

A second opportunity and a promising complement to income data and income groups is seen in consumption and expenditure data. While income is rather related to people's employment status and opportunities, other income sources such as remittances, as well as consumption and expenditure data, typically reveal how foci shift after a disaster strikes and where households start to reduce expenditures.

This adds a further information dimension as it can highlight consumption priorities and shifts in different situations, potentially pointing towards underlying well-being constraints and related impacts on other social protection dimensions. For instance, the response to a disaster may be to stop paying school fees in order to be able to afford food or reconstruction materials. Such situations may not become apparent if income is not affected or when only the household expenditure level is being observed, but only when expenditure subgroups are being identified and observed separately. An analysis on this level of detail is deemed very feasible and sensible based on the experiences observed with the analysis of income levels.

Finally, as outlined in the preceding subchapters, data from the Global Exposure database for GAR 2015 (GEG-2015), with its spatial and temporal resolution, allows us to showcase the feasibility of an application of this methodology to non-monetary assets. However, results obtained with global data sets can be greatly enhanced by using local data. This is especially true with regard to establishing the relationship between expected impact and hazard intensity. In the case of lacking or limited local data, expert interviews can be a valuable source to validate assumptions as well as the analysis results.

5 "The poverty gap index (P1) measures the extent to which individuals fall below the poverty line (the poverty gaps) as a proportion of the poverty line. The sum of these poverty gaps gives the minimum cost of eliminating poverty, if transfers were perfectly targeted. The measure does not reflect changes in inequality among the poor. The squared poverty gap index (also known as the poverty severity index, P2) averages the squares of the poverty gaps relative to the poverty line." (Jonathan Haughton and Shahidur R. Khandker, 2009, p. 67).

3.2.2. Impact on access to health services

Relevance for ASP

Tropical storms have affected more than 629 million people over the course of the twentieth century (Doocy and others, 2013), and due to the exacerbation of climate change, it is expected that mortality and morbidity due to tropical storms will continue to rise. Thus, it is important to consider the potential impact of tropical storms on human health (Mitchell and others, 2014) and their impacts on physical health infrastructure. Damage to health infrastructure and a limited sick bed capacity could seriously jeopardize the progress made to guarantee the right to health as a human right. The findings of this social protection dimension can support in guiding contingency and response planning for exposed infrastructure as well as identify necessary bed capacities and areas where those might be needed in preparation for a tropical storm.

Theoretical framework

The effects of tropical storms on the health system vary. They range from effects that exert direct pressure on the health sector, such as storm-related mortality, injuries, infectious disease outbreaks, and psychosocial effects; to those that are indirectly associated as consequences arise from failures in the infrastructure of health facilities, such as transportation shortages, disruption of public health services and job loss (Carthey and Chandra, 2007; Shultz and others, 2005).

Most of the literature found on the impacts of tropical storms on the health system consisted of epidemiology papers with a primary focus on describing/evaluating the impacts on mortality and injury patterns. A good example is a comprehensive review by Marchigiani and others (2013) in which physical injury patterns due to tropical storms are analysed and categorized into: prior to impact, impact phase, immediate post-impact phase and long-term post-impact phase.

In addition, there is empirical research that not only describes the number and types of injuries but goes further and examines their relation to tropical storm characteristics, such as wind and gust speed. For instance, the observational, non-concurrent prospective study developed by Lin and others (2013) on the effects of tropical storms on emergency health-care demands (an increase in the workload of emergency departments) in Taiwan. The authors identified the most important characteristics of tropical storms that could act as predictors of increased demand: intensity, simultaneous heavy rainfall and direct landfall. Another example is the retrospective observational study by Rotheray and others (2012) of the epidemiology of injuries due to twelve tropical storms that have passed over Hong Kong from 2003 to 2009. They linked the characteristics and timing of tropical storms with emergency departments' patient injury data to show the timing of injury in relation to tropical storms' average hourly wind speed, maximum gust, rainfall and time of closest proximity (Rotheray and others, 2012).

We also found, to a lesser extent, papers related to describing failures in the infrastructure of health facilities due to tropical storms, mostly in the sense of how these failures affect effective medical response and health-care facility preparation response (Carthey and Chandra, 2007; Marchigiani and others, 2013; Shultz and others, 2005). However, we could not identify any paper that specifically links tropical storm characteristics to damage to health facility infrastructure.

Data and Methodology

The main objective of this social protection dimension is to assess the impact of tropical storms on the health system of Nusa Tenggara Barat and Nusa Tenggara Timur. To achieve this, two different sub-indicators were used to determine the functionality and general status of the health care systems present: 1) physical damage to health care facilities, and 2) increase in hospital admissions.

Health facilities

The objective of this indicator was to assess the changes in the functionality of health facilities as an impact of a tropical storm. In other words, how many facilities would experience damage to their infrastructure if they were hit by a tropical storm?

Since the damage of the health facilities is linked to the intensity of the tropical storm, it is necessary to know the location of the facilities in order to establish the number of hospitals that could be impacted. To this end, we used the distribution of health facilities in Nusa Tenggara Barat and Nusa Tenggara Timur obtained from the Agency for Health Human Resources Development and Empowerment, Ministry of Health.[6]

The relationship between damage to infrastructure and the intensity of a tropical storm was taken from Unanwa and others (2000) and was calibrated using local data for Indonesia. Specifically, for validation, we used the number of health facilities damaged due to tropical storms by district for each of the two provinces, from 2004 to 2020; obtained from the National Board for Disaster Management, Indonesia.[7]

Therefore, the distribution of health facilities in the two provinces together with its georeferenced location, at a resolution of 5x5 km, was used as the input for CLIMADA.

Hospital admissions

Estimating the probable hospital bed occupancy through increased hospital admissions following a tropical storm is a key component in assessing whether the health system in place would be prepared for such an event. Using georeferenced data to estimate the increase in hospital admissions and capacities further helps to identify where capacities are lacking and where a capacity should suffice. For that, this indicator assesses the expected increase in daily hospital admissions in relation to a tropical storm.

To develop this indicator, we used the GAR 2015 database (de Bono and Chatenoux, 2015), which includes information on the total population and the number of private and public beds per 1,000 people in gridded points with a resolution of 5x5 km. As we did not make any distinction between public and private beds, we added them to obtain the total number of beds per 1,000 people. To obtain the actual number of beds per grid point, the beds per 1,000 people were divided by 1,000 and multiplied by the respective population of each grid point. After calculating the total number of beds per grid point, that number was multiplied by the average daily admissions (21% of the number of beds).

6 Accessible at http://bppsdmk.kemkes.go.id/info_sdmk/peta.php

7 Accessible at https://dibi.bnpb.go.id/kwilayah/index

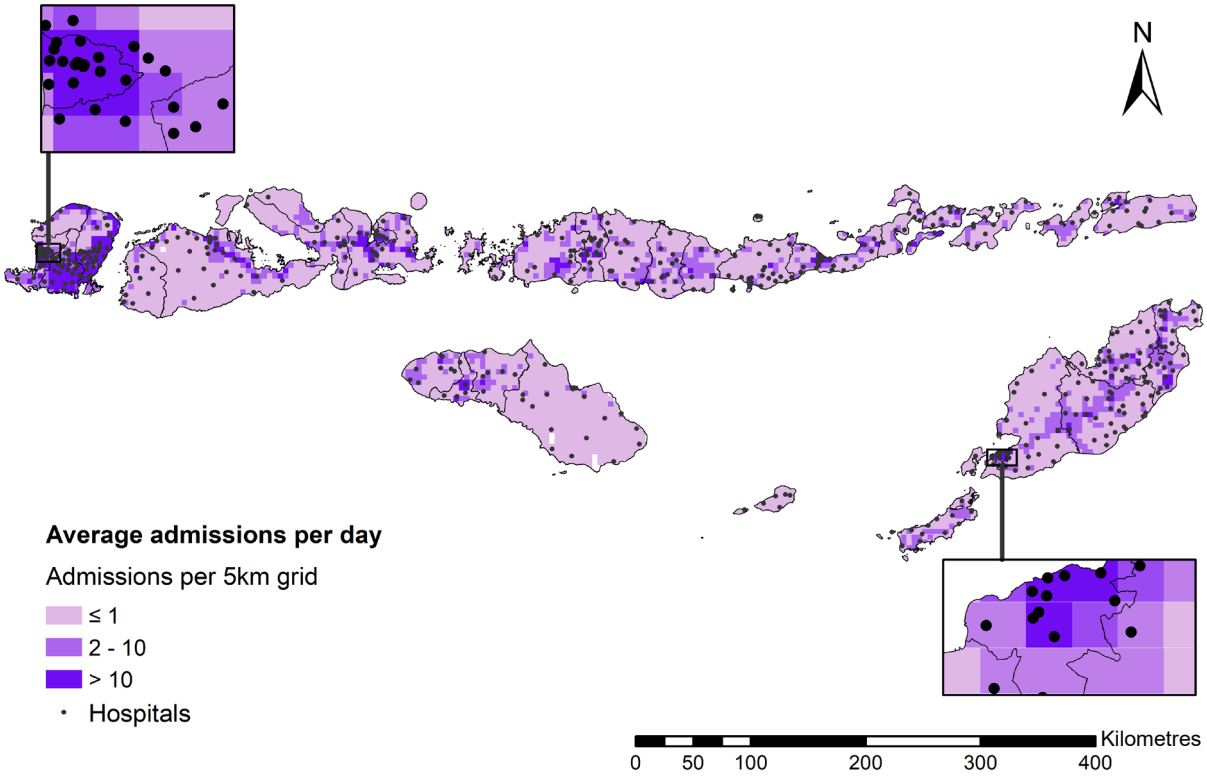

Figure 11: Access to health services: Grey points depict locations of health facilities. Shades of purple indicate average hospital admissions per day in the given 5x5km grid.
Sources: National Board for Disaster Management, Indonesia, and own calculations.

The average admissions per day (21%) was estimated using data from Ensor and Indradjaya (2012), including the average bed occupancy rate (75%), and the average length of stay (3.6 days)[8]. The relation between relative risk of injury and the intensity of a tropical storm was taken from Rotheray and others (2012) and was calibrated using local data for Indonesia. Specifically, for validation, we calculated the number of injured people due to tropical storms by district for each of the two provinces, from 2004 to 2020; obtained from the National Board for Disaster Management, Indonesia.[9] Figure 11 shows both locations of health facilities as well as average hospital admissions per day in the respective 5x5km grid.

Hence, the average admissions per day in the two provinces together with its georeferenced location, at a resolution of 5x5 km, was used as the input for CLIMADA, while the output of the modelling exercise represents the estimate of additional admissions per grid point.

8 The value cited here, 3.6 days, is the average for Nusa Tenggara Timur from 2010/11. The used source (Ensor and Indradjaya, 2012) did not provide data for Nusa Tenggara Barat. For simplicity in this proof of concept, the same value is used for Nusa Tenggara Barat to showcase feasibility. For further improvement of the results, local and more recent data would be necessary.

9 Accessible at https://dibi.bnpb.go.id/kwilayah/index

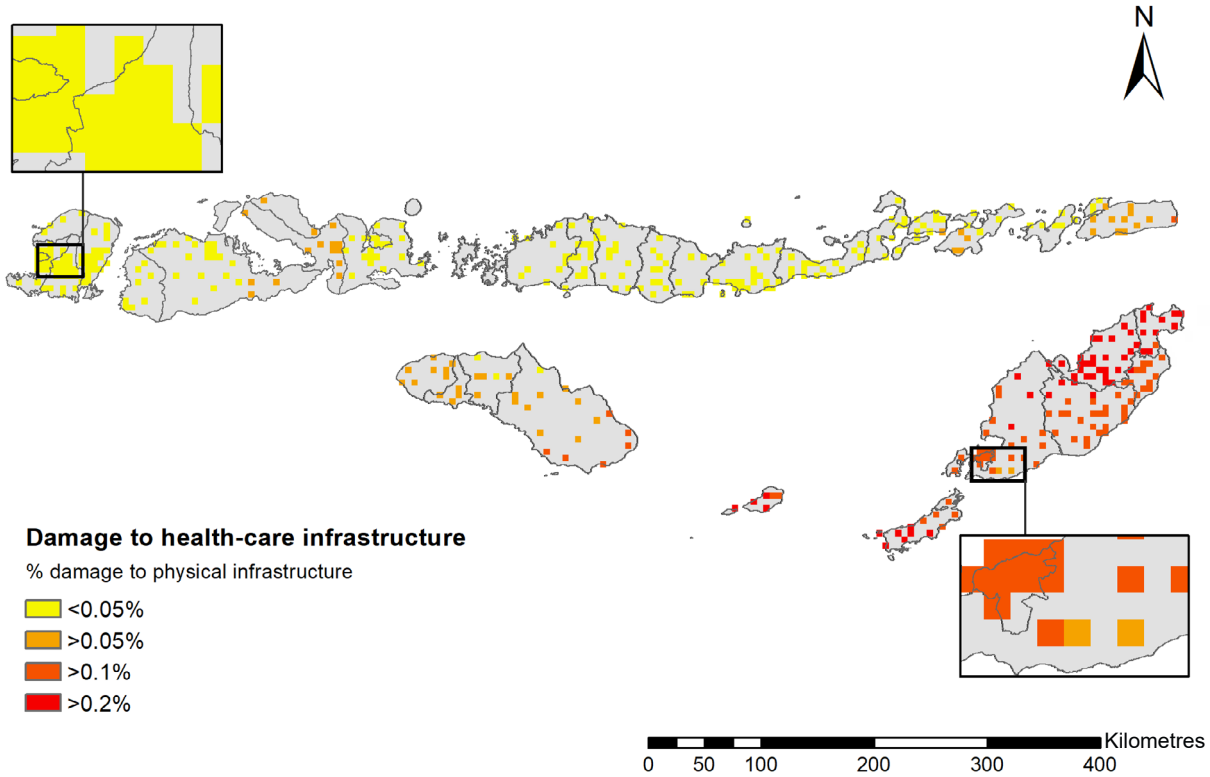

Figure 12: Impact on health-care centres: Shades of yellow and red indicate the percentage of physical damage to hospitals per 5x5km grid.

Results

In this section, we describe the outcome of CLIMADA using the asset described above. As before, a probabilistic set of tropical storms based on the behaviour of regional historical events was calculated. In regions where the maximal wind speed is highest, damage – in our case, the number of additional admissions to health centres due to strong winds and the impacts on facilities – is likely to increase. The model connects the location of individuals and health-care centres with the intensity of wind speeds and calculates the resulting damage. Hence, depending on their location, individuals and health-care centres can be impacted differently.

Health facilities

Figure 12 shows the annual expected damage of tropical storms to hospitals. In every 5x5km grid, the percentage of physical damage is highlighted. Considering the total value of a health centre (US$1 million to over US$100 million) and the number of health centres in a 5k grid in urban areas, a 0.2% amount of damage might be extremely consequential. Unfortunately, to this point, no monetary values for the individual facilities have become available. As seen before, Timor is especially affected with the strongest damage in urban areas. Considering its density of hospitals, the region can expect multimillion dollars' worth of damage on a yearly

average caused by strong winds alone.[10] Such damage is likely to put the infrastructure and therefore the whole health-care system under great pressure.

Hospital admissions

Figure 13 (p. 53) shows the annual expected damage of tropical storms to additional admissions to hospitals. In every 5x5km grid, the number of people injured directly or indirectly by a storm is highlighted. The Timor isle is especially affected, with the strongest additional admissions appearing in urban areas. With more than 1,000 additional patients for a storm event, hospitals and health-care personnel are likely to be overwhelmed considering the actual infrastructure and require alternatives to redirect patients to cope with the extra pressure.

Outlook: possible applications for policy

The capacity of health institutions to cope with the extra demands for services after disastrous events is a key factor to determine the resilience of social protection systems. Saturation in medical services needs to be avoided if quality treatment is to be provided to those who get injured. Using estimates of the increase in demand on hospital admissions, decision makers and policymakers can arrange temporary emergency facilities that support the provision of services during emergency periods. Similarly, by estimating the expected damage to health facilities, governments can pursue financial tools that make available the necessary resources for reconstruction in a timely fashion.

As part of our research, we identified seven regulations from the Republic of Indonesia whose implementation could benefit from an estimation of the impact of tropical storms and other natural hazards on health institutions. These regulations are as follows:

1. Ministry of Health (2001). Minimum Standards for Managing Disaster and Refugee Health Problems

2. Ministry of Health (2007). Technical Guidelines for Managing Health Crisis Due to Disasters

3. Ministry of Health (2008). Field Hospital Management Guidelines for Disasters

4. Ministry of Health, Center for Health Crisis. (2016). Health Crisis Management Review Book.

5. Decree of the Minister of Health No. 145 of 200. Guidelines for Disaster Management in the Health sector.

6. Minister of Health Regulation No. 75 of 2019. Health Crisis Management

7. Regional Regulations Of East Nusa Tenggara Province Number 16 the Year 2008 Concerning Disaster Management Implementation

   a. Article 5 concerns the form of health services during a disaster and the form of activities carried out to recover the health of the affected community

10 For instance, cost estimates for a General Hospital Type C, which has a capacity of up to 300 beds, range around IDR 137 billion (~ US$ 9.6 million) according to the Hospital classification based on Minister of Health Regulations no 30 / 2019. A potential 0.2% amount of damage therefore translates to IDR 274 million.

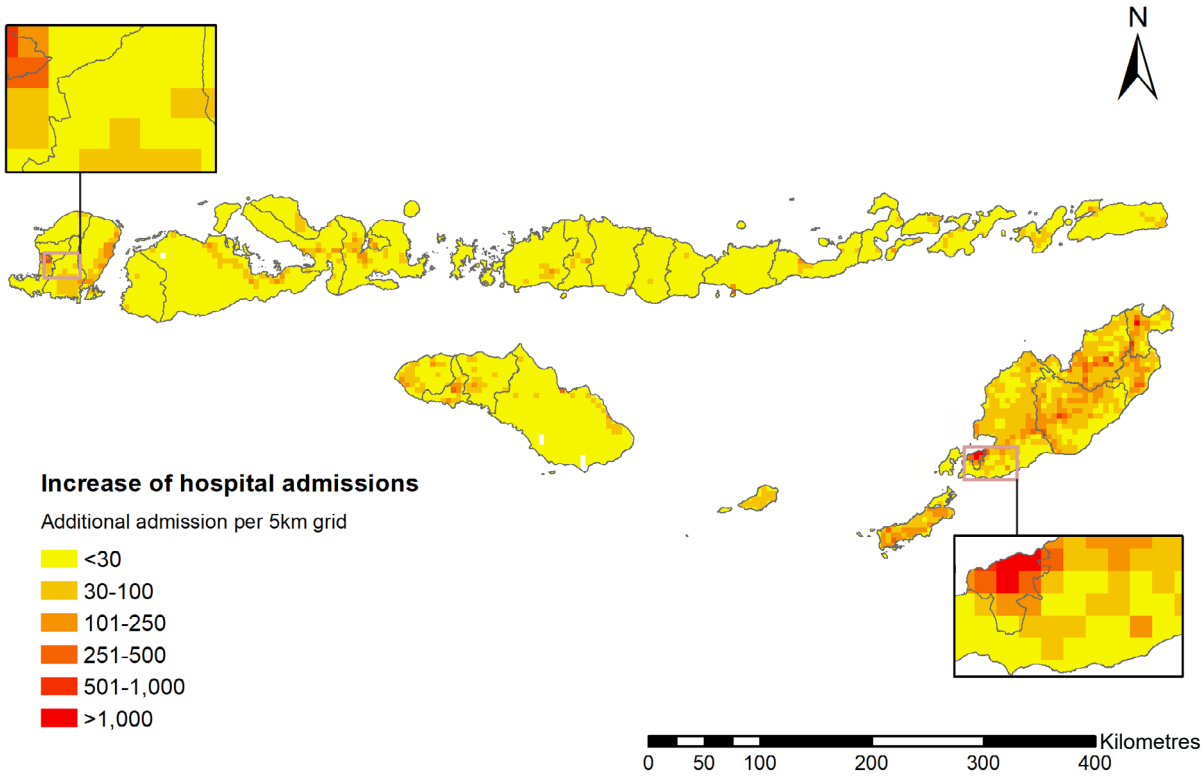

Figure 13: Impact on access to health services: Shades of yellow and red indicate the number of additional admissions to hospitals per 5x5km grid.

Additionally, through the estimation of the discussed indicators in this section, the Indonesian government can develop better strategies to advance in SDG 3.d: Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks, specifically, indicator 3.d.1 on health emergency preparedness.

Next steps

This section shows that the stress on hospital capacity and its infrastructure after a disastrous event can be quantified and modelled. Several assumptions are made to accommodate the study's scope and resources.

Possible improvements in future analyses applying the here proven approach would include a more detailed disaggregation

of health facilities (i.e. primary, secondary and tertiary level hospitals typically have different capacities as well as different tasks in the health-care system). Their specific characteristics also influence their geographical reach and thus how many people experience a loss in access to health services if a disastrous event occurs.

The applied hazard model for tropical storms relies on wind speed as the scale to measure hazard intensity, and thus all estimations of damage and impacts refer to wind speeds only. Health facilities may also be vulnerable to excess rain (and related flooding) triggered by tropical storms. Taking this second characteristic of a storm into account during a more comprehensive analysis would have the potential to provide significant information to decision makers.

Finally, although the estimation of impacts on admission rates and bed occupancy are very informative, they could be considered in light of the actual pandemic and its strain on health-care services. Using more recent and potentially more localized data, for instance on a lower administrative level, may significantly improve the results and provide a much better overview of the actual location of the facilities

Keeping those types of potential for improvement in mind, the results and methodology presented here showcase the usefulness of CLIMADA and ECA in estimating annual expected damage to the health care system infrastructure and capacity in different locations and greatly helps in identifying potential weak links in health-care provision.

3.2.3. Impact on access to education

Relevance for ASP

Human capital is essential for growth, and education is vital for building human capital (Rush IV, 2014); it is a dimension of multidimensional poverty (Trujillo, 2019). Therefore, education plays a vital role society's overall growth and development and in reducing poverty. Inaccessibility to schools after a disaster could hinder learning opportunities and generate additional stress on households. Thus, it is crucial to utilize analytical tools to understand how tropical cyclones impact access to education.

The initial findings of this study can provide a basis for planners to select safe areas for setting up temporary schools following disasters. As a result, students would have continued access to education. Likewise, adaptation measures can be planned and developed for school infrastructures exposed to natural hazards. Finally, strategic reforms and interventions to establish a resilient education system, thus meeting the aim of SDG 4, which is quality education, could be developed using the results from the model.

Theoretical framework

References to impacts of disasters on education are mostly publicly available in the form of post-disaster assessments. The generally applied Post Disaster Needs Assessment (PDNA) framework is based on PDNA guidelines (GFDRR, 2013). The approach analyses the effects and impacts of disasters to

identify recovery needs based on human, sociocultural, economic and environmental perspectives. Information on the impacts of disasters is collected on a sector-by-sector basis (Esler, 2015, 2016). For example, the PDNA report for Tropical Cyclone Winston in Fiji estimates losses and damage to education facilities in monetary terms. The damage suffered by the education sector includes damage to buildings, furniture and equipment, and education resources. In comparison, losses include costs for temporary learning spaces, cleaning, debris removal, student transportation to alternative schools, and counsellors for staff and students. In addition, some of the schools had gardens of their own for producing staple crops and vegetables. The losses sustained by the gardens were also included in the assessment (Esler, 2016).

Similarly, in the PDNA report, the impacts of Tropical Cyclone Pam on the education sector in Vanuatu are presented in monetary value. In addition, the damage to infrastructure, furniture, teaching materials and instruments has been assessed (Esler, 2015). In the case of Mozambique, the PDNA for Cyclone Idai's impact on the education sector has been conducted in monetary terms (Trujillo, 2019). All three PDNA reports include the impact of educational losses and damage to social and human sectors. However, these assessments are qualitative and lack quantitative analysis.

In terms of scientific literature, Rush IV (2014) studied the impacts of disaster on school enrolment and the consequences of disasters on Indonesia's district level. Two data sets for the study were collected, respectively. The study includes different events, such as floods, strong winds, droughts and landslides. The results of the study showed disaster impacts school enrolment negatively. In the Caribbean region, the impacts of hurricanes on school achievement were studied by Spencer and others (2016). The majority of the tools utilized focused on post-disaster analysis for tropical storms. However, there was a lack of proper frameworks designed for risk preparedness.

Additionally, as presented in the review above, assessments typically focus on damage in monetary terms rather than the quantification of reduced access to education in the affected area.

Data and methodology

The locations of education facilities and students attending schools were required to establish a relationship between affected students and the wind speed of a tropical storm. The damage curve developed, showing impacts on school infrastructure vs wind speed, was provided as an input for the model. The initial modelling results aim to identify the school buildings that would potentially be damaged due to the wind gusts of a tropical storm. Subsequently, the number of impacted students based on the results from the previous step needs to be estimated. Numerous data on the spatial location of schools are available online. For this study, data provided by OCHA (2020) was selected. The number of students was acquired from the GAR 2015 data set. Each grid point of the data set (5x5 km resolution) provides the number of students per total population as shown in Figure 14 (p. 56). The students were assigned to schools in the Nusa Tenggara region based on the spatial location of the school points and the GAR grid using ArcGIS.

For modelling purposes, education facilities were not disaggregated into different categories: elementary, junior, vocational, senior high school or private vs public. Therefore, the number of students assigned to each school is a general approximation based on the total number of pupils per grid point as the sum of both public and private schools due to the fact those were provided separately by the GAR database. For model validation, another relationship was developed — damage to school infrastructure vs the wind gusts. Data for damage to schools between 2002 and 2021 were obtained from the National Board for Disaster Management, Indonesia.[11]

11 https://dibi.bnpb.go.id/kwilayah/index

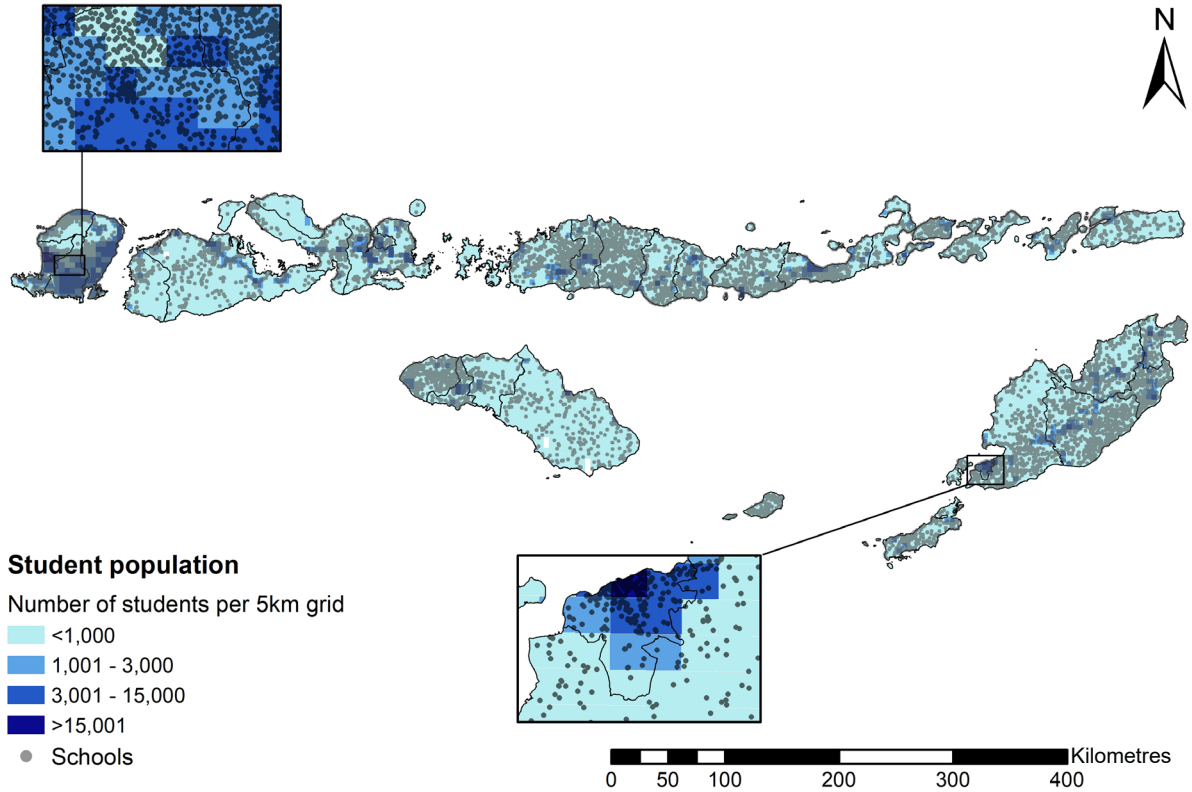

Figure 14: Access to education: Grey points indicate the location of an education facility. Shades of blue depict the number of students per 5x5km grid.

Results

In this section, we describe the outcome of CLIMADA using the asset described above. As before, a probabilistic set of tropical storms based on the behaviour of regional historical events was calculated. In regions where the maximal wind speed is highest, damage – in our case the number of students and pupils affected – is likely to increase. The model connects the location of individuals and schools with the intensity of wind speeds and calculates the resulting damage. It is assumed that the more damage is inflicted on a school, the lower the service level offered by this school. Therefore, students attending a school that has been damaged have automatically reduced access to education proportional to the damage of the school. Depending on their location, schools and therefore students can be impacted differently.

Figure 15 (p.58) shows the annual expected damage of tropical storms on students. In every 5x5km grid, the number of students directly affected by a storm is highlighted. The Timor isle and urban centres are particularly affected, with the largest number of affected students in urban areas. With numbers rising up to over 50,000 students affected in certain areas, storms represent grounds for concern in the study area.

Outlook: possible applications for policy

Protecting the access of students to education after a disastrous event is fundamental to their development. It is also important with regard to working parents. Estimating the number of students expected to be affected by natural hazards, like tropical storms, and locating the facilities that are most at risk therefore provides useful information for decision makers and policymakers planning response plans and adaptation strategies. It helps them define, for example, their guidelines for temporary education centres during the recovery phase to reduce or avoid school interruption. Similarly, when planning risks reducing investments, quantifying the potential number of affected students could inform the prioritization process among schools in risk areas.

In the specific case of the Republic of Indonesia, we identified the following three regulations whose implementation could benefit from an estimation of the expected number and location of affected students by a given hazard.

1. Regulation of the Ministry of Education and Culture Number 67 of 2016 à Amendment To Regulation Of The Minister Of Education And Culture Number 72 the Year 2013 Concerning Provision Of Special Services Education

    a. Several articles in this regulation regulate several provisions on how to provide special education services during disaster emergency situations

2. Regulation of the Ministry of Education and Culture Number 33 of 2019 concerning the Implementation of the Disaster Safe Education Unit Program

    a. This regulation is about efforts to prevent and manage the impact of Disasters in Education Units starting from the pre-disaster, during the disaster, and post-disaster stages

3. Guideline for providing education in emergency situations 2018. This guideline provides concepts and mechanisms for providing education in emergency situations

Additionally, an estimation of affected students could inform progress on SDG 4: Quality Education by reducing the potential losses in attendance to schools and other educational facilities and protecting the progress gained in accessibility through different initiatives.

Next steps

Similar for health facilities, the results presented here highlight the general feasibility of assessing access to education. To address access to education in greater detail, building on the proven approach here, several additions are recommended.

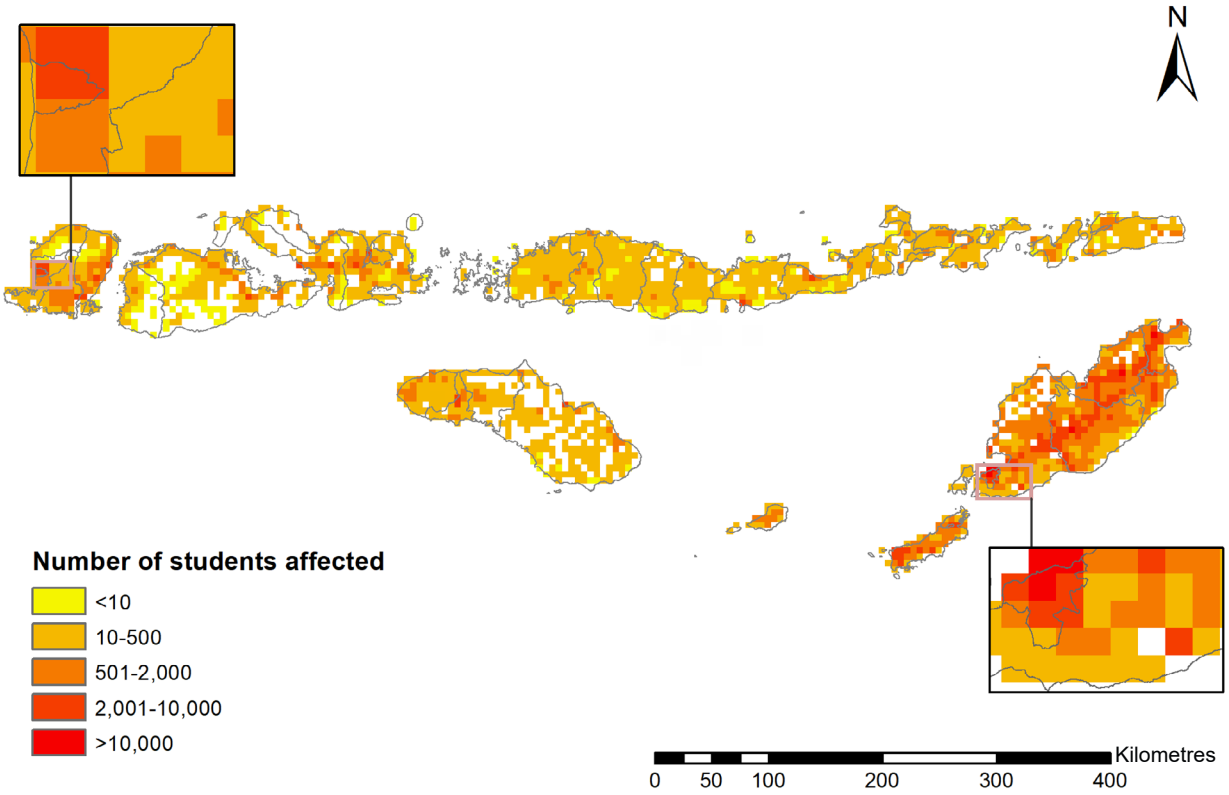

Figure 15: Impact on access to education for students: Shades of yellow and red indicate the number of affected students in a 5x5km grid.

With better data on schools, including the exact number of students per facility, disaggregated by gender and age, and the type of education facility (kindergarten/ nursery, primary, secondary, tertiary, vocational, etc.), more targeted conclusions can be drawn on possible impacts. The type of a given education facility may provide valuable information about the building materials used and thus its sturdiness, which can support the development of detailed damage-hazard intensity relationships (damage curves).

Combining different types and different age groups further helps to divide pupils more evenly to the various facilities and therefore better estimates how many and where pupils are affected by limited access to education. Detailed on-the-ground surveys would add further details to the local situation while also contributing valuable data on actual impacts on access to education due to tropical storms for validating the damage-hazard intensity relationship.

3.2.4. Impact on mobility

Relevance for ASP

Transportation is essential for social growth, as well as for economic and commercial activities. Disruption of access to transportation causes a disturbance in the daily life of people as travel times increase, if travel is at all possible. As a result, cascading effects, such as inaccessibility to education, health facilities, other social services and commercial hubs may arise. Hence, to analyse the impacts of a tropical cyclone on accessibility to transportation, this social protection dimension was selected as an example of key infrastructure. Road networks further have the distinctive characteristic of being widespread rather than a single location, such as other point-of-service bound dimensions (e.g. health/education facilities), and thus add a separate perspective in this proof of concept.

Especially in remote areas, access to transportation is crucial yet often scarce. The existing transportation networks link these areas to others. Due to lack of access to proper transportation after a disaster, these communities are most vulnerable to loss of basic needs, such as health services or commercial hubs. Additionally, delays in the provision of relief materials is more likely in these areas. Based on this study's results, a comprehensive preparedness, response and recovery management plan can be developed. Similarly, in line with SDG goals (SDG 11), analyses like these can guide in establishing a sustainable, safe, efficient and resilient transportation network.

Theoretical Framework

Numerous examples of research have been carried out and reports have been published to understand tropical storms' impacts on roads and transportation. However, the majority of these are economic analyses. After the occurrence of disasters, in this case tropical storms, the damage caused by the disaster is analysed and economic losses and damage are determined. For example, in Dominica, rapid damage and impact assessment (RDIA) was conducted to assess the impacts of Tropical Storm Erika in 2015 (GFDRR, 2015). In addition to the damage and losses caused by high wind speeds from tropical storms, the assessment included floods and landslides induced by the disaster. The losses and damage by sector were estimated in monetary value. The objective of RDIA was to provide a base for reconstruction and financing strategy.

Similarly, Post Disaster Needs Assessments (PDNA) were carried out in Vanuatu for Tropical Cyclone Pam (Esler, 2015), in Mozambique for Cyclone Idai (Trujillo, 2019) and in Fiji for Tropical Cyclone Winston (Esler, 2016). The PDNA is a bottom-up approach and is carried out to analyse disaster impacts and identify recovery needs, encompassing both macroeconomic and social impacts. The assessment contains detailed studies on impacts and quantified monetary value losses and damage to transportation. In addition, PDNA provides recovery and reconstruction strategies. Different sectors are prioritized, and the costs of recovery and reconstruction are distributed accordingly (Esler, 2015, 2016; Trujillo, 2019).

The World Bank (2011) conducted a study on adaptation cost to extreme weather events due to climate change in Bangladesh. Cyclonic storm surges and related coastal floods were considered to assess the inundation depth of coastal areas in Bangladesh. Adaptation costs to monsoon floods and storm-surge inundation are presented in the report. According to Izzo and others (2010), the flooding caused by Tropical Storm Noel heavily affected road infrastructure, and parts of the highway were inundated by floodwaters, thus obstructing vehicular movement in the Dominican Republic. Losses and damage from floods caused by storm surges and heavy rainfall linked to cyclones are presented in PDNA reports for Tropical Cyclone Pam, Cyclone Idai and Tropical Cyclone Winston.

In Hainan Province, China, Yang and others (2016) assessed transportation network functional damage caused by tropical cyclones by developing an analytical tool. The analysis is done following four steps that include: 1) The simulation of wind fields for tropical cyclones to extrapolate impacted areas; 2) Measurement of highway network efficiency and calculation of functional highway network damage; 3) Statistical analysis for the identification of spatial factors of tropical cyclones inducing functional damage to the highway network, and 4) Risk analysis and computation of return periods for different damage levels. The relationship between spatial characteristics of tropical cyclones and functional damage to highway networks was quantified using regression models.

Case studies on economic analysis of losses and damage, adaptation and mitigation costs of climate-induced disasters are abundant. Most of the studies and assessments have been on the economic impacts of tropical storms on the transportation sector. However, studies on the impacts of a tropical cyclone on access to transportation are limited. Therefore, for this analysis, a different approach is being developed as outlined in the following section.

Data and Methodology

To determine loss of mobility for every given storm, the relationship between the length of a damaged road and wind speed needs to be determined. According to Yang and others (2016), the impacts of natural hazards on a transportation network could be divided into functional and physical damage. The damage to road infrastructure due to tropical storms globally was considered in initial research with the aim of establishing a satisfactory relationship between damage, quality and type of road, and wind speed/tropical storms. However, the data and literature reviewed provided insufficient information to establish such a correlation. Given the scarcity of available data at this stage, only functional damage to the transportation network was considered. In this case, road blockages due to fallen trees provide an excellent proxy for loss of mobility and can be directly linked to strong winds.

Rainforest and eucalyptus tree species are found in the Nusa Tenggara region. The latter has a relatively high density in the region (Almulqu and others, 2018; Windadri and Rosalina, 2020) and was thus chosen as the core subject of research. Lindsay and Dickinson (2012) studied the effects of cyclonic winds on various eucalyptus and rainforest tree species in the tropical north of Queensland, Australia. For this study, the storm resistance of the trees was considered. However, for simplicity in the modelling process, only eucalyptus trees were assessed and the differences in resistance due to the age of the trees were not represented. A damage curve was generated with tree resistance vs wind speed.

The model further assumes that there are no trees around roads outside of forested areas for simplicity. Thus, only roads passing through or along four types of forest land covers[12] – converse production forest, limited production forest, production forest and protected forest – were selected for

12 Accessible at: https://energydata.info/dataset/indonesia-small-hydro-gis-database-2017

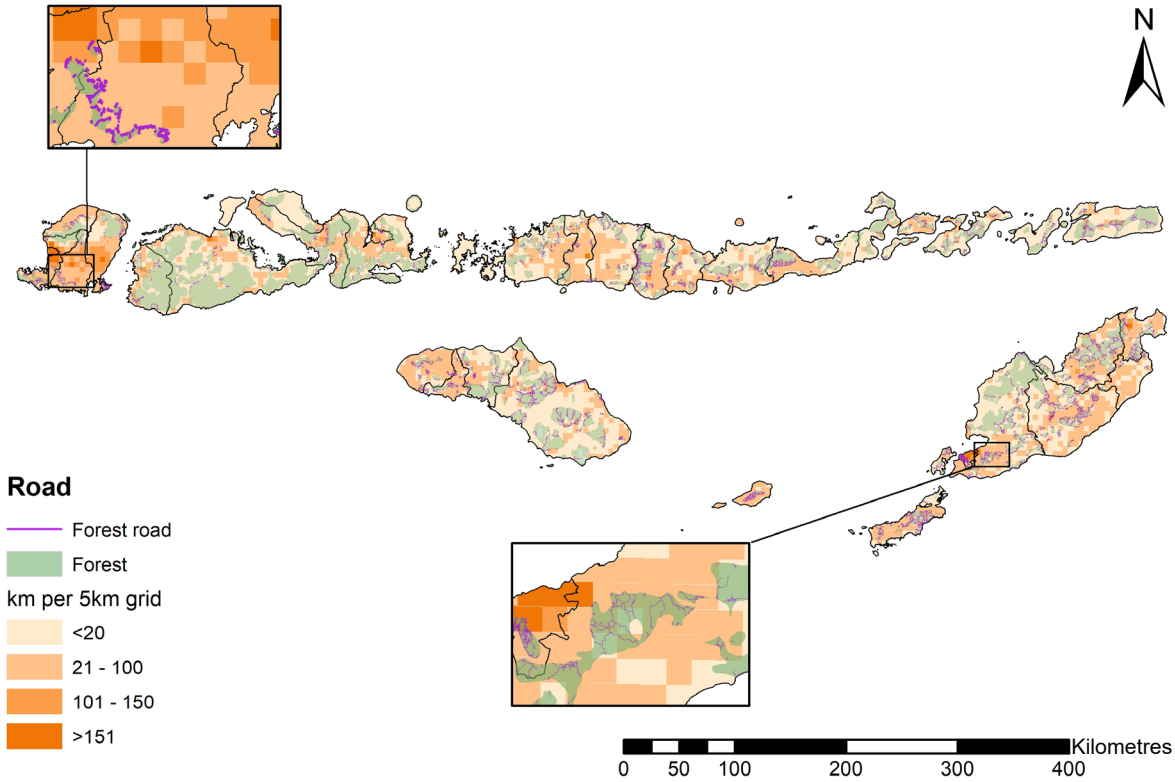

Figure 16: Access to transportation: Roads in forested areas are marked in purple. Green: forest areas. Orange shaded areas depict the total length of road in a given 5x5km grid.

further analysis. The selected road sections[13] were divided into a 5x5 km grid based on the GAR 2015 grid of the same resolution as presented in Figure 16.

The total length of forest roads for individual grids was calculated and provided as an input for the modelling tool CLIMADA. The model results inform about the length and location (based on the grid) of blocked roads due to fallen trees caused by high wind speeds. In other words, the length of usable roads after the tropical storm can be determined.

The objective behind the analysis is to understand how tropical storms affect accessibility to transportation.

Results

In this section, we describe the outcome of CLIMADA using the asset described above. As before, a probabilistic set of tropical storms based on the behaviour of regional historical event was calculated. In regions where the maximal wind

13 Accessible at: https://data.humdata.org/dataset/hotosm_idn_lsi_roads

speed is highest, damage to trees is expected to be the highest form of damage. The CLIMADA model connects the location of trees and roads (in forested areas) with the intensity of wind speeds and calculates the resulting damage. In our case, damage equates to a loss of mobility (i.e. road blockages are directly connected to the percentage of trees affected by winds). Hence, depending on their location, trees and therefore roads are impacted differently.

Figure 17 (p.64) shows the annual expected loss of mobility in the region of interest. In every 5x5km grid point, the length of roads indirectly affected by a storm is highlighted. The Timor isle is particularly affected. Even without considering trees in urban areas, or blockages by airborne electric grids and other debris, these results highlight how storm events can affect populations and in which areas the damage is expected to be most significant.

Outlook: possible applications for policy

Mobility is key for both emergency response and to enable a swift recovery after the occurrence of a disastrous event. Identifying blockage potential can inform adaptation strategies to protect the main road infrastructure and the selection of alternative paths for emergency response plans. Also relevant for the latter, estimations of blockage removal needs after the hit of a tropical storm can inform the assignment of trucks or other vehicles for road cleaning purposes.

An example of a regulation from the Republic of Indonesia, whose implementation could benefit from this estimation of road blockage due to tropical storms is presented below.

1. Regulation of National Disaster Management Agency No. 11 of 2008 concerning Guidance for Rehabilitation and Reconstruction Post Disaster

2. Regulation of Ministry of Public Works and Housing No. 13 of 2011 concerning Maintenance Procedure for Street

Additionally, the Indonesian government could follow progress on SDG 11: Sustainable cities and communities; especially target 11.2: Safe, affordable, accessible, and sustainable transport systems, which reflects on accessibility to appropriate transportation by all.

Next steps

This section showcases the validity of our approach using CLIMADA to quantify loss of mobility in the research area. Even with limited data availability, a sound analysis can be drawn from the results, and the spatial distribution of the damage provides additional key information for decision makers. Nevertheless, several improvements can be made. For instance, the inclusion of local expert opinions is likely to provide more detailed information about forest types, tree density and other characteristics of the forests in question and their composition.

Additional information on forest and tree types could greatly increase the predictive power of the model. Furthermore, light poles, power lines and other debris that follow the road network could be added to such an analysis. Historical damage data generally help to critically improve the model. This could possibly be obtained and validated through intense stakeholder engagement with local communities, experts and (sub-) regional governments.

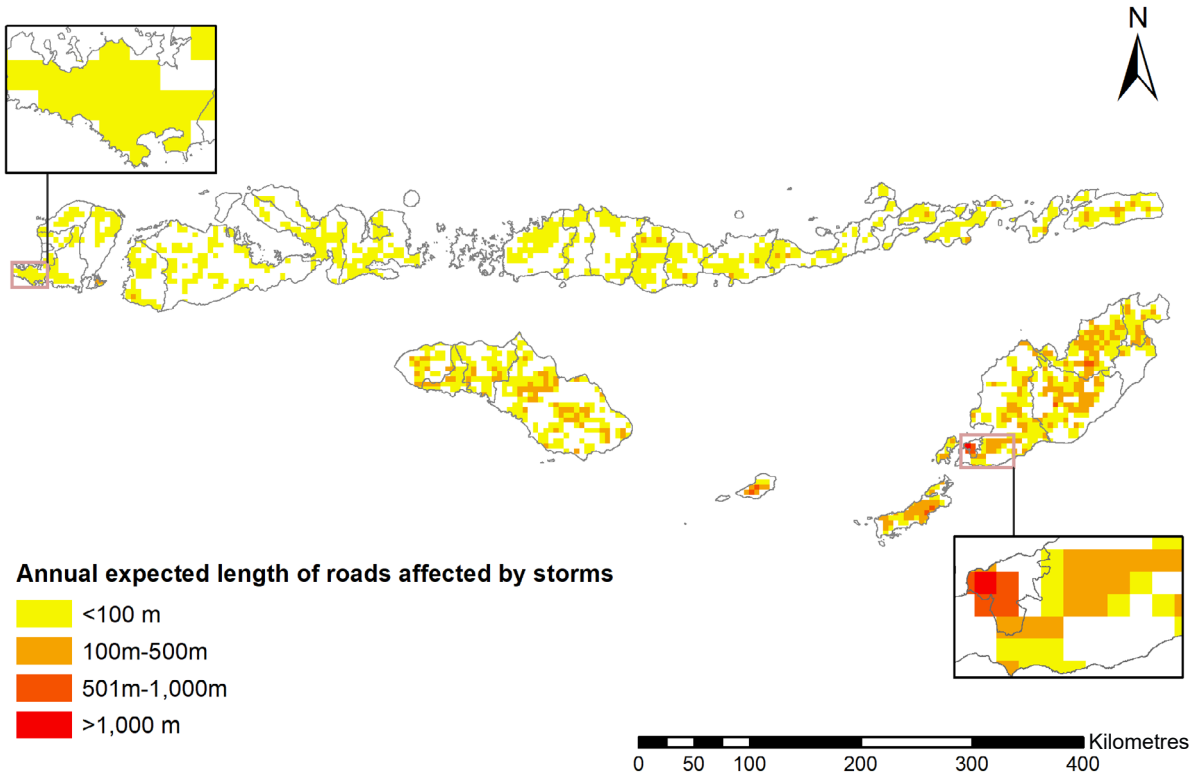

Figure 17: Impacts on mobility: Shades of yellow and red indicate the length in metres of roads in a 5x5km grid.

Finally, deeper insights into peoples' mobility and how they are affected by tropical storms are valuable for refining the model and adjusting it as closely as possible to local circumstances. For instance, for shorter distances with limited cargo, people may opt to walk or cycle, if this is not already the case, a decision which would be less affected by blocked roads. Additionally, limited provision and availability of fuel, either due to affected gas stations or limited supply, can significantly impact mobility of people and goods alike even when roads are not blocked. Investigating such additional perspectives on mobility and access to transportation can provide further insights and reveal potential bottlenecks in the sector.

Similarly to the other SPDs, the impacts of floods related to a tropical storm could also be included in the future for modelling purposes. This would allow results to better reflect the full effect caused by this natural hazard on mobility.

3.3 Findings on the feasibility of quantifying ASP with ECA

In this chapter, we describe our experience testing the feasibility of implementing ECA and CLIMADA to quantify the impact of extreme events on non-tangible, non-financial assets such as access to health and/or education and reduction of income and/or mobility. These social protection dimensions, or SPDs, are core components of an ASP approach, and quantifying the potential impacts of extreme events on them is key for allocating the necessary resources to guarantee their resilience. The proof of concept presented above successfully showed how the ECA framework and its probabilistic modelling tool CLIMADA can appropriately model SPDs and spatially illustrate results to inform policy design and implementation on Adaptive Social Protection.

For our case study in the Nusa Tenggara region, we identified physical proxy locations that could be linked to the selected dimensions, used the available gridded data in combination with local data to better represent the distribution of the selected indicators and set a baseline methodology that can be scaled up and allow for countrywide analyses. Notwithstanding, more targeted lower-scale analyses focusing on, for example, urban areas or specific branches of a social protection system are also feasible.

Aside from providing evidence of the suitability of ECA to quantify impacts on ASP, the numerical results from this proof of concept are presented mostly for illustrative purposes. The results, and therefore their usability, would benefit greatly from a stakeholder engagement approach, leading to larger and better data sets, local knowledge inclusion and higher ownership among beneficiaries. At this stage, the results still need to go through a validation process that reflects on the set of assumptions made during the modelling phase and the uncertainties related to the use of open data from global sources, such as the GAR report, as opposed to locally collected data. Only through true integration of local authorities, academia and beneficiaries can the potential of the ECA methodology and CLIMADA be fulfilled and properly inform policymaking and decision-making.

4. Conclusion and Recommendations

After identifying information needs for analysing risks and impacts in the context of ASP - exemplified by tropical storms (Chapter 2, p.19) - and assessing the feasibility of quantifying some of the key risks and impacts using the ECA framework (Chapter 3, p.36), this chapter concludes by considering the utility of CADRAT-ASP and its overall value. It highlights the potential relevance of CADRAT-ASP for assessing risks and impacts, thereby supporting the implementation of ASP (Chapter 4.1), and presents recommendations for research, policy and practice regarding how to use the results of this study in future applications (Chapter 4.2, p.68).

4.1. Conclusion

One of the main results of this study revealed that the range of relevant risks and potential impacts of tropical storms on community well-being is very broad and reaches beyond the usual scope of risk assessments. Risks in the context of ASP were identified to be interconnected, resulting from various risk drivers and potentially leading to cascading effects, including impacts on communities that are not directly exposed. This suggests that the results of traditional risk assessments might reflect an incomplete understanding of relevant risks faced by communities. Especially, non-monetary impacts on population are understudied and seldom quantified. Such an imperfect risk understanding could undermine the efficacy of future ASP approaches. This study thereby highlights the importance of a more comprehensive risk assessment as the foundation for any ASP measure, addressing the most relevant target groups and underlying vulnerabilities to reduce the impacts of future disasters.

The CADRAT-ASP project is characterized as a feasibility study of the ECA framework to quantify non-monetary impacts of tropical storms in the context of ASP in an attempt to overcome the quantification of non-monetary risk on communities. The results of this study show that the ECA framework can provide high-quality information for decision makers to take effective ASP action, thereby increasing the resilience of communities. This model successfully assesses essential impacts, such as on health-care services in hospitals or on household incomes. Additionally, the assessment takes into account some previously identified cascading impacts, such as the threat that road blockages pose to reduce mobility and how that disrupts lives and livelihoods within a community.

CADRAT-ASP can hence be used to assess non-monetary impacts linked to the physical presence of people, assets and activities in a distinct geographic location, as well as specific primary cascading impacts on physical infrastructure. Moreover,

the uncertainties related to the valuation method of intangible assets, such as loss of future income or access to healthcare during the response phase of a disaster, are addressed by using an index approach. By offering results that reflect expected increases in poverty or hospital bed occupancy, decision makers can better incorporate social criteria when planning risk management strategies.

In contrast, other major risks and impacts have not been considered in this study or have revealed limitations for the application of the ECA framework in the context of ASP. For example, secondary cascading effects, such as the effect of reduced mobility on access to health centres, the continuation of economic activities and access to schools, have not been included in this study despite their relevance for ASP. In addition, further development of the model, such as the integration of the flood risks associated with tropical storms, would add great value. Similarly, other hazard components could be included, such as droughts, heatwaves, urban flooding or storm surges, to provide a broader overview and allow for multi–hazard risk planning. Estimating aggregated damage is often challenging but essential in reflecting real-world circumstances. Moreover, damage curves, which measure the vulnerability of the selected dimensions to a given hazard, require considerable calibration using local historical data as well as validation from experts in respective fields. It is also highly recommended that the data sets used for following iterations would be cross-referenced with locally collected data.

While the results shown in this report are highly encouraging, they also demonstrate the potential for future research needs. The use and further development of tools such as the ECA framework has indeed proven to be a beneficial approach and shows that existing tools are effective in evaluating risk and impacts, rendering the complex and time-consuming process of tool development unnecessary. Moreover, they demonstrate the importance of gaining clarity on the multiple and cascading consequences of any hazard. The findings of this study establish the basis for systematic analyses of variables that are often ignored or aggregated in sectoral assessments, such as traditional loss and damage analyses typically used when assessing climate change impacts.

4.2. Recommendations

Building on the results and lessons learned, these recommendations are shared with the intention of facilitating future research, policy and practice related to the use of the CADRAT-ASP study to support resilience-building. Recommendations are clustered around four central themes: mainstreaming the CADRAT approach into ASP, data and information needs for the application of CADRAT-ASP, methodological advancements of the ECA framework to support ASP and optimizing the use of CADRAT-ASP for improved resilience-building.

Approach

- A joint risk understanding needs to be developed as a basis for applying risk analytics for ASP. Risk understandings significantly differ between different actors involved in ASP and those applying risk analytics. Therefore, a joint understanding of risks and impacts on well-being in the context of ASP needs to be created to enable cooperation and thus align efforts to strengthen communities' resilience.

- A successful implementation of ASP requires a novel Climate and Disaster Risk Analytics Tool that builds on existing approaches. As an integrated scheme, ASP tries to overcome siloed approaches by focussing on interconnected risks and solutions. To support the implementation of ASP, new approaches and tools are hence needed that can be applied across sectors and that overcome silos. This particularly applies for the assessment of risk, which is a vital first step in the design of ASP interventions. New tools such as CADRAT-ASP are thus needed to bridge gaps and silos.

- Linking existing approaches is important to combine knowledge to support ASP implementation. Many approaches to support resilience-building are well established and known. Where possible, it is recommended to make use of these approaches and the knowledge and experiences linked to them rather than developing completely new tools. This could also help to engage important stakeholders and increase their ownership. For CADRAT-ASP, the use of impact chains combined with the modelling approach of the ECA framework is advised as it enables the assessment and quantification of interconnected risks and cascading impacts, including on non-physical assets.

Data and information

- Integration of existing data through cooperation of and exchange among stakeholders provides vital data and information to apply risk analytics in the context of ASP. Data and information availability in Indonesia is adequate. However, data is often stored in ministerial data systems and sharing is often limited to bilateral, on-demand exchange. Increased data sharing between federal, regional and local government institutions, as well as between different sectors, increases access to vital data for the application of data-intensive risk analytics. To support data exchange, a joint database, such as Satu Data, could help to provide an overview of all available data and information relevant for CADRAT-ASP.

- Additional data and information are needed and data quality principles must be ensured to allow for improved modelling results to better support decision-making. Despite decent data availability in Indonesia, much information is still not collected that would be useful to further advance modelling outcomes. For example, little information is collected after disasters on damage and specific service interruptions, which makes it difficult to estimate vulnerability levels and thereby challenges impact modelling. More comprehensive data collection is hence needed that also considers quality principles, including data accuracy, timeliness, relevance, resolution and disaggregation, to improve modelling outcomes.

- Local data collection and validation are vital to refine and adjust modelling outcomes for risks and impacts. Global data sets are very useful to gain a broad overview and make general assumptions on risk patterns. However, they cannot accurately determine specific local conditions. Therefore, local data needs to be collected to complement and validate lower resolution data. This can inform hypothetical risk assessment scenarios by better and more accurately estimating expected impacts to improve locally specific interventions.

- Data protection needs to be considered throughout all stages of risk assessments to ensure data privacy. Despite the outlined need to collect high-resolution data to best inform policymaking, it is important to ensure data protection principles to avoid violations of personal privacy. Data on the household level, such as income or health, must therefore be aggregated to ensure that this information is kept confidential and cannot be used by unauthorized parties.

Methodology

- Include a larger set of SPDs and proxies, especially those covering critical infrastructure. For instance, access to electricity could not be included in the proof of concept because information on the type of grid connections at different locations on the islands was not available. Estimating the impact of storms over the main grid would overlook households that rely on home generators or other mini-grid solutions. This dimension should also not be dismissed in the future as it is a key component of many other SPDs. If properly assessed in collaboration with local stakeholders, better knowledge of such key infrastructure can bring valuable information to decision-making processes.

- Carefully select SPDs of interest and connected physical proxies (e.g. buildings, road infrastructure, etc.). Identifying physical proxies for the chosen SPDs early on during project implementation allows for a thorough analysis and distinction of subclasses of the respective proxy. For instance, different types of education facilities may have different student capacities and rely on differing construction material. Such type-specific characteristics influence both the potentially affected population and the damage curve depicting the intensity-damage relationship.

- Improve precision by selecting additional indicators for each social protection dimension. This will enrich the assessment and provide further information to support risk-informed decision-making for ASP. For instance, when changes in employment were incorporated, they greatly enhanced results on income reduction. The information provided by the proof of concept on wealth is limited to the number of people who fall into the lowest income group and may now be facing poverty conditions. If changes in employment status were also modelled, especially within the informal sector, the impacts of tropical storms on households living below the poverty line before the disaster could also be captured in the results and offer some guidance for decision makers.

- Consider climate and socioeconomic scenarios to ensure long-term validity of the results. While the results presented here focus on modelling the potential impacts of tropical storms in the present, ECA can incorporate probable changes in climatic and socioeconomic conditions when estimating the damage of disastrous

events. In addition to climate change, population and economic growth increase expected losses due to future extreme weather events. This means investments in preventative measures should be informed with information reflecting these types of changes. With the ECA framework, decision makers can further include the assessment of adaptation measures in order to estimate their potential to avert damage.

- Further include the financial impacts of disruptions of services beyond standard financial impact calculations. For instance, the financial impact of road closures stretches far beyond the cost to repair or clear affected roads. There are further implications resulting from the disrupted provision of social services. Modelling such secondary and interconnected effects requires further research to both establish interrelationships and develop a module capable of modelling those effects. To support stakeholders in making decisions towards interventions or measures that are most cost-effective, it is important to quantify the total potential financial impacts.

- Pay attention to feedback loops that potentially exacerbate risks. While the examples presented in this report are rather linear, based on an impact chain from a given hazard to potential impacts on well-being, the reality is more complex. Cascading and secondary impacts as well as potential feedback loops can impact risk levels and ultimately the number of people in need of ASP. By collecting data from disaster events such linkages can be assessed, and thus analyses can be further advanced.

Uptake of CADRAT-ASP

- Align and embed CADRAT-ASP into broader ASP implementation strategy. The implementation of a risk analytics tool only makes sense if it is an integral part of ASP. While analytics are needed to inform the development of meaningful ASP measures, the tool in return needs to be designed in a way that speaks to particular demands and local conditions. In the context of Indonesia, it is hence of vital importance to consider CADRAT-ASP within the broader ASP roadmap and other guiding documents, as well as embedding it within the four Building Blocks.

- Awareness of all involved stakeholders is a precondition for the successful uptake of CADRAT-ASP. This requires that capacity-building is tailored to the various stakeholder groups to reach a comprehensive understanding of the overall methodology, the selected SPDs and the risks faced. In addition, awareness-building around the potential of CADRAT-ASP is needed to facilitate the acceptance of such a tool, inform stakeholders about its comparable advantages and overcome potential barriers. This includes transparent information for potential target groups to familiarize them with the approach, increase understanding and promote the use of participatory approaches both to validate data and to test possible measures for their acceptance, including to further improve the design of ASP measures.

- Stakeholder engagement is key to guarantee the quality of the results. The closer the collaboration with local stakeholders, experts and academia, the more precise input data will be provided to CLIMADA, the modelling platform underpinning the ECA framework. With the support of local

governments, the information needed to determine the relationships between the intensity of the hazard and the impacts on SPDs can be appropriately collected and higher quality results can be provided for decision-making. Ownership from the beneficiaries of the results will be critical for the implementation of the measures identified by decision makers, and engagement of communities from early-stage involvement is the most effective way to achieve commitment.

- A multi-stakeholder approach needs to be followed to better understand the existing conditions and thereby target investments in the most meaningful, yet locally feasible, ASP action. To do so, cooperation formats should be established which bring together stakeholders involved in the different steps of CADRAT-ASP. Such formats should be used to critically reflect on the methodology and potential need for adjustments, as well as to clarify the roles and responsibilities of the different stakeholders. These efforts will serve to strengthen cross-sectoral collaboration and facilitate coherent approaches ultimately promoting the successful implementation of ASP.

- Enhance institutional capacities to enable application of CADRAT-ASP. Successful integration and uptake of CADRAT within the Indonesian ASP strategy will require continuous and independent probabilistic risk modelling capacities by national and regional governments. Capacity development is a key activity in enabling respective stakeholders to conduct sectoral, needs adjusted analyses. The enhancement of institutional capacities and the alignment of implementation strategies, based on strong stakeholder engagement, are preconditions to achieving this objective.

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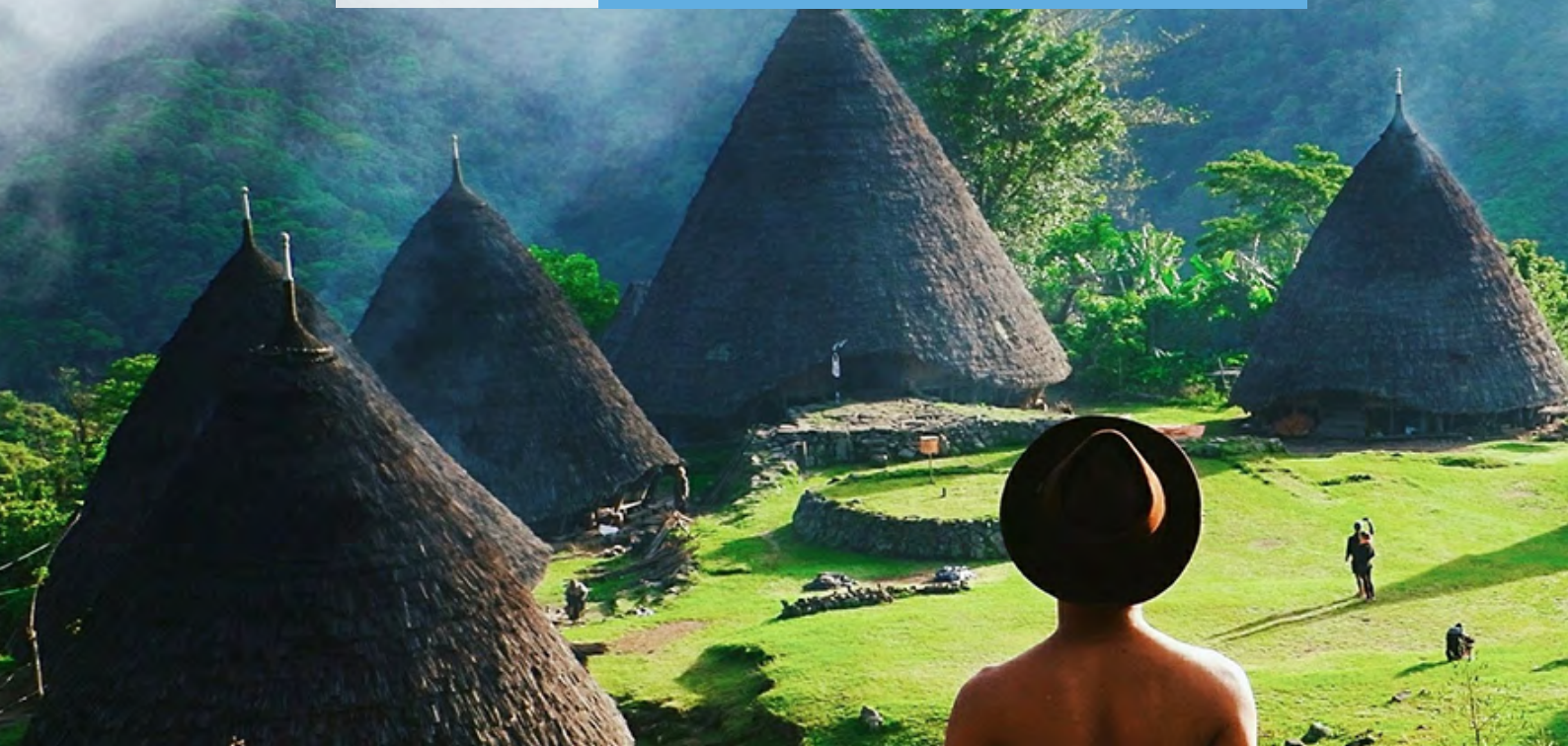
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