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Chapter 1
Resilience Assessment at the State Level Using the Sendai Framework

Melissa De Iuliis, Omar Kammouh, and Gian Paolo Cimellaro

Abstract The multitude of uncertainties of both natural and man-made disasters have prompted an increased attention in resilience engineering and disaster management. To overcome the effects of disastrous events, such as economic and social effects, modern communities need to be resilient. Natural disasters are unpredictable and unavoidable. While it is not possible to prevent them and protect individuals and societies against such disasters, modern communities should be prepared by incorporating both pre-event (preparedness and mitigation) and post-event (response and recovery) resilience activities to minimize the negative effects after a severe event. Resilience indicators may be fundamental to help the planners and decision-makers to develop strategies and action plans for making communities more resilient. This chapter presents a quantitative approach to estimate the resilience and resilience-based risk at the state level. In the proposed method, the resilience-based risk is a function of resilience, hazard, and exposure. To evaluate the resilience parameter, data provided by the Sendai Framework for Disaster Risk Reduction (SFDRR) are used. The framework is developed using resilience indicators with the primary goal of achieving disaster risk reduction. To use those indicators in the resilience assessment, it is necessary to define the impact and the contribution of each indicator towards resilience. To do that, two possible methods to combine and weight the different SFDRR indicators are presented: Dependence Tree Analysis (DTA) and Spider Plot Weighted Area Analysis (SPA). The proposed approach allows the decision-makers and governments to evaluate the resilience and the related resilience-based risk (*RBR*) of their countries using available information.

Keywords Resilience · Risk management · Recovery · Sendai framework · Disaster reduction

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1 Introduction

The emergence of stressors such as population growth, urbanization, natural and man-made disasters, and resource scarcity, has brought a remarkable attention to the concept of resilience in modern communities facing growing challenges from severe events. Over the years, the focus has shifted to managing and reducing disaster risk, as it is often impossible to predict. Disaster events can be managed through hazard emergency planning to make modern communities more resilient so that they can absorb the impacts and recover quickly after disasters and reduce the time of recovery (De Iuliis, Kammouh, Cimellaro, & Tesfamariam, 2019a, 2019b; Kammouh, Cardoni, Marasco, Cimellaro, & Mahin, 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, Palermo, & Cimellaro, 2018). The concept of resilience is multidimensional, and therefore involves the various subjects of different disciplines (Balbi, Kammouh, Pia Repetto, & Cimellaro, 2018; Bonstrom & Corotis, 2014; Chang, McDaniels, Fox, Dhariwal, & Longstaff, 2014; Cimellaro, Renschler, Reinhorn, & Arendt, 2016; Cimellaro, Zamani-Noori, Kammouh, Terzic, & Mahin, 2016), from psychology, sociology, and economics to engineering and environmental research. The term was first developed in the ecological field in 1973 by Holling, defined as "*a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships among populations or state variables.*" In engineering, the concept of resilience is "the ability of social units (e.g., organizations, communities) to mitigate hazards, contain the effects of disasters when they occur, and conduct recovery activities in a way that minimizes social disruption and mitigates the effects of future earthquakes" (Bruneau et al., 2003; Cimellaro, Reinhorn, & Bruneau, 2010; Cimellaro, Renschler, et al., 2016; Cimellaro, Zamani-Noori, et al., 2016; Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018; Zamani Noori, Marasco, Kammouh, Domaneschi, & Cimellaro, 2017). Wagner and Breil (2013) defined resilience as the ability to "withstand stress, survive, adapt, and recover from a crisis or disaster and move on quickly." In the engineering perspective, the resilience of a modern community is based on all the physical components of the system, including buildings and infrastructures, to absorb the damage caused by an external shock and restore their state before the shock (Bruneau et al., 2003; Kammouh, Cardoni, Kim, & Cimellaro, 2017; Kammouh, Dervishaj, & Cimellaro, 2017; Kammouh, Zamani Noori, Renschler, & Cimellaro, 2017; Kammouh, Zamani-Noori, Cimellaro, & Mahin, 2017; O'Rourke, 2007; Reed, Kapur, & Christie, 2009). Bruneau et al. (2003) state that resilience is based on its serviceability performance. A measurable function $Q(t)$, that depends on the variable of time, can describe the value of the community infrastructures. The performance of a system can range from 0% to 100%, where 100% means "no drop-in service" and 0% indicates "no service available" (see Fig. 1.1). The loss of resilience $Q(t)$ is the performance degradation of the system over the entire recovery period, which starts

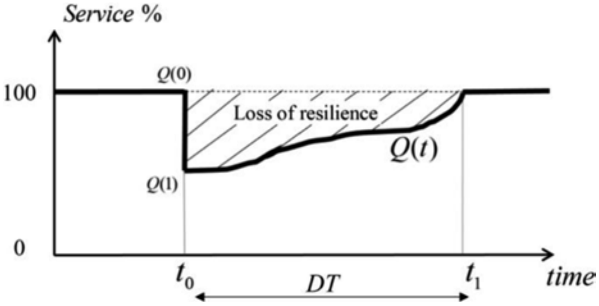

Fig. 1.1 Conceptual representation of engineering resilience

after the hazard event ends and when the functional capability returns to the initial state. Mathematically, the loss of resilience can be defined as follows:

$$\mathrm{LOR} = \int_{t_0}^{t_1} \left[100 - Q(t)\right] \mathrm{dt} \tag{1.1}$$

where *LOR* is the loss in resilience, t_0 is the time at which a disastrous event occurs, t_1 is the time at which the functionality of the system is 100%, $Q(t)$ is the functionality of the system at a given time t.

Nowadays, the concept of resilience is widely associated with disaster risk reduction. UNISDR (2005) defines resilience as "the ability of a system, community or society potentially exposed to hazards to adapt by resisting or changing in order to achieve and maintain an acceptable level of functioning and structure."

Several resilience frameworks available in the literature highlight the lack of standardization in defining resilience measurements due to the multidisciplinary context (Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018; Marasco et al., 2018; Sarkis, Palermo, Kammouh, & Cimellaro, 2018). Available resilience frameworks are often based on the indicators that are important for assessing community resilience at different levels. Some address engineering resilience at the country level (Kammouh, Cardoni, et al., 2017; Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2017; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018; Kammouh, Zamani Noori, et al., 2017; Kammouh, Zamani-Noori, et al., 2017) and some at the local and community level (Kammouh, Cardoni, et al., 2017; Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2017; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Gardoni, & Cimellaro, 2019; Kammouh, Silvestri, et al., 2018; Kammouh, Zamani Noori, et al., 2017; Kammouh, Zamani Noori, Cimellaro, & Mahin, 2019; Kammouh, Zamani-Noori, et al., 2017). Liu, Reed, and Girard (2017) proposed a framework that combines dynamic modeling with resilience analysis.

Two interconnected critical infrastructures were analyzed using the framework by performing numerical calculation of resilience conditions in terms of design, operation, and control of parameter values for specific failure scenarios. A quantitative method for assessing resilience at the state level was presented in Kammouh and Cimellaro (2018), Kammouh, Cardoni, et al. (2018), Kammouh, Cimellaro, and Mahin (2018), Kammouh, Dervishaj, and Cimellaro (2018), Kammouh, Silvestri, et al. (2018). In their approach, the data from the Hyogo Framework for Action (HFA) (ISDR, 2005), developed by the United Nations (UN), is used for the analysis. The methodology focuses on the implementation of the detailed measures at the government level through policies. Another quantitative framework for designing and measuring community resilience is the PEOPLES framework (Cimellaro, Renschler, et al., 2016; Cimellaro, Zamani-Noori, et al., 2016). PEOPLES is an extension of resilience research conducted at the Multidisciplinary Center of Earthquake Engineering Research (MCEER). The PEOPLES framework includes seven dimensions: Population, Environment, Organized government services, Physical infrastructures, Lifestyle, Economic, and Social capital (Renschler et al., 2010). Another measurement framework is the Baseline Resilience Indicator for Communities (BRIC) (Cutter, Ash, & Emrich, 2014). This is a quantitative tool that focuses on the pre-existing resilience of communities and, unlike the PEOPLES framework, is practically related to fieldwork. A qualitative framework that measures the ability to recover from seismic events is the San Francisco Planning and Urban Research Association framework (SPUR, 2009). The framework analyzes the recovery of buildings, infrastructure systems, and services.

Despite this robust literature, there is still considerable disagreement about the indicators that define resilience and the frameworks that are most useful for measuring it. As a result, approaches to assessing community disaster resilience are poorly integrated. The modeling approaches (e.g., PEOPLES framework) described above require accurate data to feed into the models to be functional, but access to this data is limited and often the accuracy is insufficient. Moreover, when unexpected events occur and not enough information is available or the previously prepared plan is not adequate, the decisions made are subjective and based on experience. The difficulties in collecting data and indicators, as well as in defining the interactions between them makes the resilience assessment so complex that it cannot be used by decision-makers and industry (Bonstrom & Corotis, 2014; Chang et al., 2014; Cimellaro, Renschler, et al., 2016; Cimellaro, Zamani-Noori, et al., 2016). The Hyogo 10-year Plan gave rise to a new framework, the Sendai Framework, developed by the United Nations (UN). The Sendai Framework is a new quantitative framework for building the resilience of nations and communities based on the implementation of the Hyogo Framework (UNISDR, 2015a, 2015b). The methodology adopted by the Sendai Framework aims to reduce disaster risk and loss of life, livelihoods, and health in the economic, physical, social, cultural and environmental assets of individuals, businesses, communities, and countries. The objective is to assist countries in implementing the framework into their laws. The main objective of this chapter is to propose a quantitative method for quantifying the resilience and resilience-based risk of countries using the results of the Sendai Framework. It is believed that the proposed methodology will enable decision-makers to learn about the state of their communities in the face of a specific event and to identify the key aspects on which the greatest effort should be placed to improve the resilience of their communities.

The remainder of the chapter is organized as follows. Section 2 describes the resilience-based risk analysis as a function of resilience, exposure, and hazard. Section 3 introduces the Sendai Framework for Disaster Risk Reduction with its global targets. Section 4 illustrates the Sendai Framework indicators and the corresponding calculation. Section 5 proposes the quantitative methodology to assess the resilience of communities. Finally, conclusions are drawn in Sect. 6 together with the proposed future work.

2 Resilience-Based Risk Analysis

The concept of resilience is associated with vulnerability in several disciplines (Klein, Smit, Goosen, & Hulsbergen, 1998). Several approaches to vulnerability measurement defined in the literature link vulnerability to the concept of risk assessment (Papadopoulos, 2016). For instance, an engineering-based damage assessment model was developed to define the vulnerability of low-rise buildings to tornadoes. The output of the model is a damage index percentage and the overall damage ratio of the building (Peng, Roueche, Prevatt, & Gurley, 2016). An important vulnerability and risk assessment tool is *Hazus*, a standardized risk assessment software developed by the U.S. Federal Emergency Management Agency (FEMA, Hazus) to estimate losses following natural hazards (Nastev & Todorov, 2013). It consists of four main models: (1) the *Hazus* earthquake model, (2) the *Hazus* hurricane wind model, (3) the *Hazus* flood model, and (4) the *Hazus* tsunami model.

While some works in the literature provide the same definitions for resilience and vulnerability (Klein, Nicholls, & Thomalla, 2003), others present different views for the two concepts (Cutter, 2016). A comparison between vulnerability and resilience on different scales is presented in Table 1.1.

Table 1.1 Comparison between vulnerability and resilience at different scale (adapted from Cimellaro, 2016)

Vulnerability	Resilience
Resistance	Recovery
Force bound	Time-bound
Safety	Bounce back
Mitigation	Adaptation
Institutional	Community-based
System	Network
Engineering	Culture
Risk assessment	Vulnerability and capacity analysis
Outcome	Process
Standards	Institution

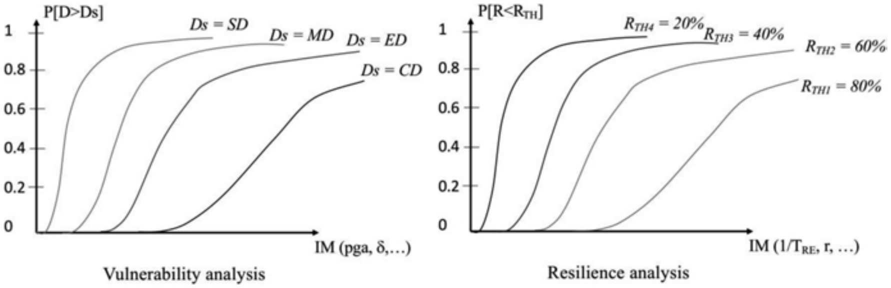

Fig. 1.2 Comparison between the vulnerability and the resilience analysis

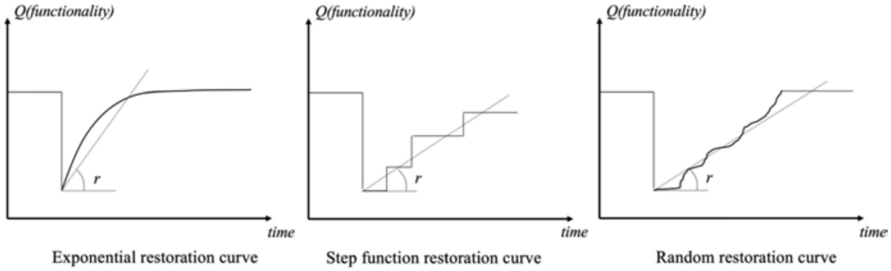

Fig. 1.3 Typical restoration curves

The differences between vulnerability and resilience at different levels suggest that resilience is more concerned with the human ability to recover from a severe event within a short period of time, while vulnerability is concerned with the capacity to withstand stress caused by natural hazards (Kammouh & Cimellaro, 2018). Since the process of resilience assessment is subject to several uncertainties, a probabilistic approach can be defined similarly to the classical vulnerability analysis. That is, in vulnerability analysis, the vulnerability of a system is determined by designing fragility curves that represent the probability of exceeding a certain damage state under different hazards. In resilience assessment, on the other hand, the fragility curves describe the probability that a system will exceed a resilience level at a given intensity. In resilience estimation, both recovery time and recovery speed r should be considered. The speed of recovery depends on several factors, such as human resources, recovery plan, and financial resources (see Fig. 1.2).

Figure 1.3 illustrates three different types of restoration curves: exponential function, step function, and random function. The rapidity of recovery r is considered as the slope of the best-fitting line obtained by applying linear regression to the restoration curve (Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018).

The aim of this chapter is to provide an index that allows countries to be compared in terms of their resilience and corresponding risk. The probability of not achieving a certain level of resilience is defined as resilience-based risk (*RBR*). While in the classical risk assessment method, risk is the combination of vulnerability, hazard, and exposure, in the proposed work, resilience-based risk is influenced

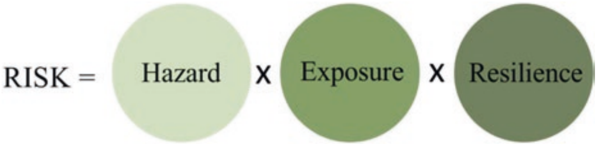

Fig. 1.4 Resilience-based risk analysis

by both the internal characteristics of a system (resilience) and the external factors (exposure and hazard). As Fig. 1.4 shows, resilience-based risk is a function of Resilience (*R*), Hazard (*H*), and Exposure (*E*). The mathematical formulation of *RBR* is given by:

$$\mathrm{RBR} = \left(1 - R\right) \times E \times H \tag{1.2}$$

A hazard is a dangerous event that can cause the loss of a line, an impact on society or health, loss of property, livelihood, and services. In this chapter, the impact of hazards is neglected due to the lack of necessary hazard maps. Exposure is the number of people affected in a hazardous area and it is taken from the World Risk Report (WRR), a study by the United Nations University for Environment and Human Security 104 (UNU-EHS). The third parameter, resilience, is determined using data from the Sendai Framework. The Sendai Framework indicators are equally weighted for ranking and scoring countries. However, in assessing resilience, these indicators need to be weighted according to their impact on resilience. Two weighted methods are used in the proposed work. The first method is based on dependency tree analysis (DTA) (Kammouh, Cardoni, et al., 2017; Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2017; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018; Kammouh, Zamani Noori, et al., 2017; Kammouh, Zamani-Noori, et al., 2017). DTA is a method that determines the correlation between components and their subcomponents (i.e., between resilience and its indicators) by assigning different weights to the subcomponents. Another method used to assign the appropriate weights to the indicators of the Sendai Framework is spider plot analysis (SPA). In this method, the spider plots are designed to define a geometric combination of the indicators. The weights of each indicator are plotted on one of the axes of the spider plot. Resilience is then computed as the area between the linked angles normalized by the total area of the shape. The resilience results obtained by each of the two methods are then used to obtain the RBR by combining them the exposure and risk hazard.

2.1 World Risk Report (WRR)

The World Risk Report is a study prepared by the United Nations University for Environment and Human Security (UNU-EHS). This report aims to rank countries around the world according to their vulnerability, exposure, and risk level by taking

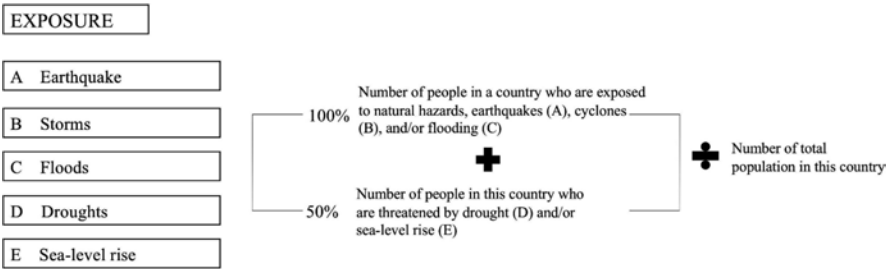

Fig. 1.5 Exposure analysis in the world risk report

various measures. In the work, the WRR is implemented to assess the exposure of the countries, and consequently, used for the resilience-based risk evaluation. Figure 1.5 shows the strategy adopted by WRR to determine the exposure of countries. The exposure is computed as a combination of the number of people exposed to the hazards of the different countries, divided by the total population of the country.

3 Sendai Framework for Disaster Risk Reduction

The Sendai Framework for Disaster Risk Reduction 2015–2030 was adopted on March 18, 2015, at the Third UN World Conference in Sendai, Japan. The Sendai Framework is the successor tool to the Hyogo Framework for Action (HFA) 2005–2015. Although the HFA was an important tool for raising awareness on disaster risk reduction, a relevant loss has occurred in the 10 years of its implementation. That is, despite the efforts, there was a high number of fatalities (about 770,000) and 1.5 billion people were affected by disaster events.

Consequently, the framework was developed to reduce the damage and loss of life, livelihoods, and health, hazard exposure and vulnerability to disasters, and increase preparedness for response and recovery from 2015 to 2030. An important aspect to consider is the data on loss and damage at different scales and levels (local, national, and regional) in the context of event-specific hazard, exposure, and vulnerability (UNISDR, 2015b).

The Sendai Framework, which is a multi-level development, emphasizes risk management instead of disaster management, which was the focus of the HFA. It also defines a list of activities that nations should follow to prevent new risks, and is based on four specific priorities for action (UNISDR, 2015a, 2015b):

- Priority 1: Understanding disaster risk, vulnerability, and exposure to hazards.
- Priority 2: Strengthening disaster risk governance, with clear institutions and budgets for managing disaster risk.
- Priority 3: Participating in DRR funding to strengthen resilience (including public and private investments that help prevent disasters).
- Priority 4: Highlighting the importance of disaster preparedness and building back better in recovery, rehabilitation, and reconstruction.

In addition, the framework sets out seven different global disaster risk reduction targets to help assess global progress towards this goal (UNISDR, 2015a, 2015b). The global targets are:

a. Substantially reduce global disaster mortality by 2030, with a target of reducing the average mortality rate per 100,000 people in the decade 2020–2030 compared to the period 2005–2015.
b. Significantly reduce the number of affected people globally by 2030, with the aim of reducing the average number per 100,000 in the decade 2020–2030 compared to the period 2005–2015.
c. Reduce direct economic loss from disasters in terms of global gross domestic product (GDP) by 2030.
d. Substantially reduce disaster-related damage to critical infrastructure and disruption of essential services, including health and education facilities, including by developing their resilience by 2030.
e. Significantly increase the number of countries with national and local disaster risk reduction strategies by 2020.
f. Significantly strengthen international cooperation in developing countries through adequate and sustained support to complement their national actions to implement this framework by 2030.
g. By 2030, significantly improve the availability of and access to multi-hazard early warning systems and disaster risk information and assessments for the population.

The targets described allow for global improvements in data collection procedures to facilitate their definition. Beyond the seven global targets, the Open-Ended Intergovernmental Working Group (OEIWG) on indicators and terminology related to disaster risk reduction has developed a list of indicators that depend on each of the seven targets and allow monitoring of progress on the targets and global implementation of the Sendai Framework. More details on the indicators for monitoring the global targets of the framework can be found in the next section.

3.1 Sendai Framework Indicators

The Sendai framework can be applied by conceptualizing its seven main targets to create a common method for measuring and assessing resilience. The creation of indicators is essential to report on progress at regional, national, and local levels and to achieve the expected outcomes of the framework and its global targets.

Following the structure of Arup's City Resilience Framework, supported by the Rockefeller Foundation, it is possible to subdivide the framework. The Arup framework is divided into four dimensions: health and well-being, economy and society, infrastructure and environment, and leadership and strategy. It can be divided into 12 goals and 52 indicators.

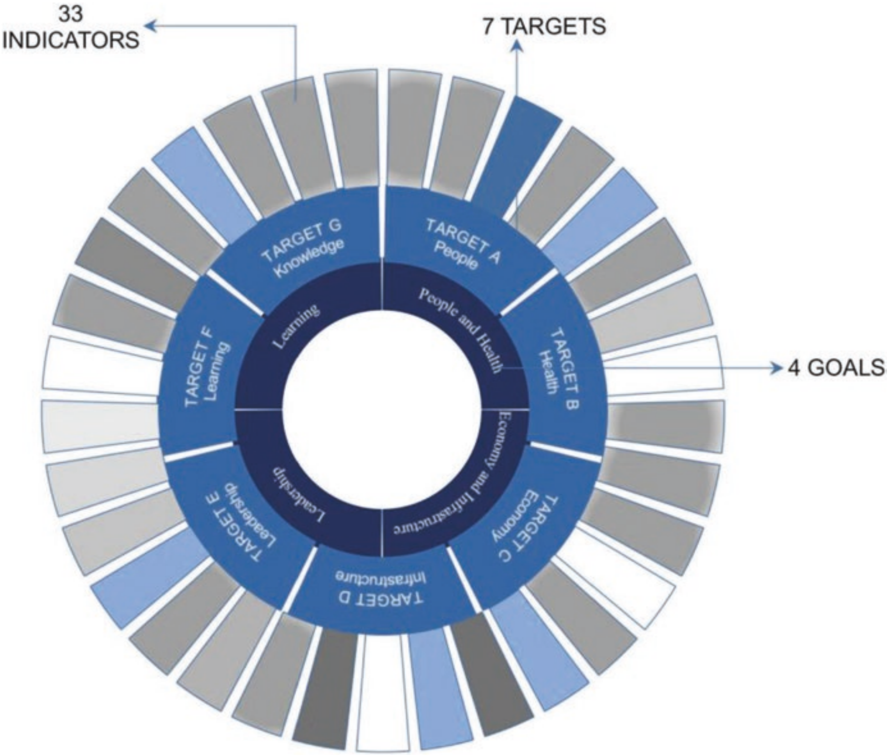

Fig. 1.6 Synthetized Sendai framework structure (adopted to ARUP, 2014)

As illustrated in Fig. 1.6, the targets of the Sendai Framework are merged with the following goals:

a. People
b. Health
c. Economy and housing
d. Infrastructure and city services
e. Leadership and strategy actions
f. Learning
g. Knowledge

The different goals are then divided into 33 indicators that are used to assess resilience at different scales, i.e., from buildings and structures to cities and countries.

4 Sendai Framework Indicators Calculation

Since damage and loss are the most important aspects of the framework, only the first four global targets (A–D) are considered. While the first two targets focus on mortality and the degree of affectedness, target C is based on capturing direct economic losses due to disasters. Finally, the target D focuses on disaster damage to infrastructure.

To calculate the losses and damages from target A to D, it is first important to determine the time dimension. That is, the disaster may change depending on the analyzed period (e.g., people heal after a certain period, reducing the number of injuries). UNIDR recommends a period of 42 days after the occurrence of a hazard event. Moreover, the resilience assessment must consider certain minimum requirements by collecting data relevant to a specific group, country, hazard, and residence. Below, is a further description for each target.

4.1 Target A: People

Target A estimates the mortality index due to a disaster, considering the number of missing and presumed dead in a 100,000 population area. Some specific minimum requirements are set for the calculation of Target A indicators. Poverty level is defined by the international poverty line of $1.90 US dollars set by the World Bank; gender is divided into female and male; age is categorized in children, adults, and elderly. Disability is categorized into with or without disability, and finally, geographic location is reduced to the municipality level.

Target A is divided into three indicators:

- A_1: Number of deaths and missing people/presumed dead people due to hazardous events per 100,000.
- A_2: Number of deaths due to hazardous events.
- A_3: Number of missing people/presumed dead people due to hazardous events.

Indicator A_1 strongly depends on the indicators A_2 and A_3 as follows:

$$A_1 = \frac{(A_2 + A_3)}{\text{populations}} \times 100{,}000 \tag{1.3}$$

where A_1 is a compound indicator, and A_2 and A_3 are directly calculated from a physical survey on the direct count of either dead people or missing people for the considered event.

4.2 Target B: Health

The Sendai Framework established the target B, which estimates the number of people affected by a disaster and their health index, considering population growth and the rise in the number of affected people.

Target B necessitates the same minimum requirements as target A, as it is concerned with people. Target B is broken down into seven indicators:

- B_1: Number of affected people by hazardous events.
- B_2: Number of injured or ill people due to the hazardous events, number of people suffering from physical injuries, trauma or cases of disease requiring the immediate medical assistance.
- B_3: Number of evacuate/relocated people after a disaster.
- B_4: Number of people whose houses were damaged by a catastrophic event.
- B_5: Number of people whose houses were destroyed by a catastrophic event.
- B_6: Number of people who received aid including food and nonfood aid.
- B_7: Number of people whose livelihoods were disrupted, destroyed, or lost.

Some of the indicators of target B may cause problems with their measurements. For instance, the number of homeless people is not always easy to define, and the number of people receiving food and medical aid is challenging to count because different ONGs, private and public entities may provide then.

B_1, like A_1, is a compound indicator obtained by adding indicators B_2 to B_6 as follows:

$$B_1 = \frac{B_2 + B_3 + B_4 + B_5 + B_6}{\text{population}} \times 100{,}000 \tag{1.4}$$

It is important to note that indicators B_2, B_3, and B_6 are derived from the hazard dates, whereas indicators B_4 and B_5 are calculated by multiplying the number of an average number of occupants per house of each country (AOH):

$$B_4 = n\,\text{houses} \times \text{AOH} \tag{1.5}$$

4.3 Target C: Economy and housing

Target C is concerned with the economic losses incurred because of the disaster. That is, disaster losses and damages are not always caused by humans, they also impose an economic burden that must be accounted for. It assesses whether the city/country economic resources are sufficient to deal with the disaster. Domestic, agricultural, and infrastructural services are all considered to estimate the damages they have suffered and the amount of the damages.

Target C can be classified as:

- C_1: Direct economic loss about the global gross domestic product.
- C_2: Direct agricultural loss due to hazardous events.
- C_3: Direct economic loss.
- C_4: Direct economic loss due to commercial facilities damaged or destroyed.
- C_5: Direct economic loss caused by damaged houses.

- C_6: Direct economic loss caused by destroyed houses.
- C_7: Direct economic loss caused by damages to critical infrastructures.
- C_8: Direct economic loss as a consequence of a degraded environment.
- C_9: Total insured direct losses caused by hazardous events.

Indicator C_1 is a compound indicator consisting of the summation of the number of economic losses from various sectors, starting from agricultural loss (indicator C_2) up to economic losses due to environmental degradation (indicator C_8). C_1 is then divided by the GDP, which is a measure of economic resources. The formula for obtaining indicator C_1 is shown in Eq. (1.6).

$$C_1 = \frac{C_2 + C_3 + C_4 + C_5 + C_6 + C_7 + C_8}{\text{GDP}} \tag{1.6}$$

where indicators are calculated by considering the size of the facility (e.g., small, medium, and large evaluated by national ranges), cost per unit (e.g., per square meter, per kilometer, per hectare), the number of damages to the unit, and the number of infrastructures.

4.4 Target D: Infrastructures and City Services

Target D is responsible for repairing damaged infrastructure and restoring essential services that have been disrupted because of a major event. Target D is characterized by different indicators based on the infrastructure and service under consideration. Target D indicators are:

- D_1: Damage to critical infrastructures.
- D_2: Number of health facilities destroyed or damaged by hazards.
- D_3: Number of educational facilities destroyed or damaged by hazards.
- D_4: Number of transportation units and infrastructures destroyed or damaged by hazardous events.
- D_5: Number of damaged or destroyed bridges.
- D_6: Number of damaged or destroyed airports.
- D_7: Number of damaged ports.
- D_8: Number of damaged electricity plants or transmission lines.
- D_9: Number of time basic services disrupted by hazards.

Indicator D_1, as well as the previous targets' first indicators, is a compound indicator. It needs data from the other indicators and the number of times interruption of damage occurs. It is calculated as follows:

$$D_1 = \frac{\left(D_2 + D_3 + D_4 + D_5 + D_6 + D_7 + D_8 + D_9\right)}{\text{population}} \times 100{,}000 \tag{1.7}$$

4.5 Target E: Leadership and Strategy Actions

To calculate Target E, some basic data from different nations must be collected. Nations should have (*a*) a clear legislative and regulatory policy in all sectors, public and private, defining each responsibility; (*b*) precise time and roles of the administrator to deal with disaster risk situation; (*c*) precise measurements and objects to prevent a risk; (*d*) a clear technical and financial management to cope with the disaster; and (*e*) periodic assessments to report the progress on developing a strategy.

Target E considers:

- E_1: Number of countries that adopt and implement the national DRR strategies in line with the Sendai Framework for Disaster Risk Reduction 2015/2030.
- E_2: Percentage of local governments that adopt and implement the local DRR strategies in line with the Sendai Framework for Disaster Risk Reduction 2015/2030.

Indicator E_1 can be obtained by weighting the data described above to determine the impact each data presents on E_1. That is, indicator *a* shows a 40% influence on E_1, indicator *b* for 20%, indicator *c* has 10% impact, indicator *d* of 20%, and finally, the weight of indicator *e* is about 10%.

Therefore, E_1 is equal to:

$$E_1 = 0.4 \times a + 0.2 \times b + 0.1 \times c + 0.2 \times d + 0.1 \times e \tag{1.8}$$

Indicator E_2 measures the number of local governments that adopt a disaster risk reduction strategy by counting the total number from a survey.

4.6 Target F: Learning

Target F refers to the calculation of the number of international cooperation to sustain and implement the framework. Target F is divided into four indicators (Eslamian & Eslamian, 2021):

- F_1: Number of countries that support the implementation of the framework.
- F_2: Number of international institutions that support financially the implementation of the framework.
- F_3: Number of international institutions and regional multi-stakeholder partnerships established to build a disaster risk reduction.
- F_4: Number of countries with international and regional initiatives for the exchange of technology and innovation in disaster risk reduction.

The compound indicator F_1 is used to determine the cooperation from different sectors: financial and economic resilience (F_2), building resilience (F_3), and science and innovation resilience (F_4). In this case, the indicator F_1 is the sum of:

$$F_1 = F_2 + F_3 + F_4 \tag{1.9}$$

4.7 Target G: Knowledge

Target G can be classified as:

- G_1: Number of countries that have the multi-hazard early warning system.
- G_2: Number of countries that have the multi-hazard monitoring and forecasting system.
- G_3: Number of people who are covered by and have access to multi-hazard early warning system per 100,000.
- G_4: Number of local governments having a preparedness plan (including EWS) or evacuation plan with standard operating procedures.
- G_5: Number of countries that have multi-hazard national risk assessment with results in an accessible, understandable and usable format for stakeholders and people.
- G_6: Number of local governments that have a multi-hazard risk assessment or risk information, with results in an accessible, understandable, and usable format for stakeholders and missing people.

Indicator G_1 is a compound indicator, and it is calculated using equally weighted indicators from MHEWS.

Indicators are defined through a detailed survey that includes a series of questions necessary to obtain information on the resilience progress of each country. Table 1.2 lists the types of questions and the answers, which can be Yes/No or description text, that were presented in the survey for indicator A_2. After each country's authorities have completed the questionnaire, it is returned to the UN. Each country tracks its progress on a five-point scale for each indicator, with one point indicating slow progress, and five points indicating rapid progress in that area.

Table 1.2 Questions asked by UN to assess the indicator A_2

Question	Answer type
Do you collect the number of deaths attributed to disasters?	Yes/No
Do you collect the number of deaths attributed to disasters disaggregated by the event?	Yes/No
Do you collect the number of deaths attributed to disasters associated with a hazard type?	Yes/No
Do you collect the number of deaths attributed to disasters disaggregated by location?	Yes/No
Do you collect the number of deaths attributed to disasters disaggregated by age?	Yes/No
Do you collect the number of deaths attributed to disasters disaggregated by sex?	Yes/No
Do you collect the number of deaths attributed to disasters disaggregated by disability?	Yes/No

5 Resilience-Based Risk Assessment

As previously stated, indicators in the Sendai Framework have the same weights, implying that they have the same level of importance. However, because the importance of the indicators varies, they must be weighted before being used in the resilience evaluation. To do that, two different weighting methods are applied to the Sendai Framework indicators, and the corresponding resilience results are compared. In the following, the two weighting methods are described in detail.

5.1 Dependence Tree Analysis (DTA)

The dependence tree analysis method subdivides the components into subcomponents by capturing their correlation. The DTA is implemented to combine the Sendai framework indicators based on their contribution to the resilience assessment.

The DTA method starts with the identification of all potential components that influence the main output. The most common method for identifying these components is to brainstorm or refer to lessons learned (Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018).

The components, which are classified into main components, intermediate components, and basic components, are presented in the dependence tree according to the way in which they are logically related to one another. The main component is known as the task required to get out of a system and it is located at the top of the dependence tree. The intermediate components are those required to achieve the main component. Finally, the basic components are those that cannot be divided into subcomponents. Furthermore, depending on the importance of the component, it may appear multiple times in the dependence tree.

Figure 1.7 depicts the arrangement of the components in the dependence tree. In the resilience assessment, the main component is referred to as resilience, the intermediate components are the targets, and the basic components that cannot be divided into any further subcomponents are the SFDRR's indicators.

The analysis starts with the identification of the indicators and their relationships. The Sendai Framework assigns a numerical score to each indicator with a maximum value of 5 ($I_{\max} = 5$). Equation (1.10) is then used to normalize the indicators' scores for their maximum value. Finally, resilience is computed using the DTA by combining the scores of indicators in such a way that the indicators in series are multiplied, while the indicators in parallel are weighted averaged (Kammouh, Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018). As a result, the DTA method's main output is a normalized resilience that ranges between 0 and 1.

$$I_{i,N} = \frac{I_i}{I_{i,\max}} \tag{1.10}$$

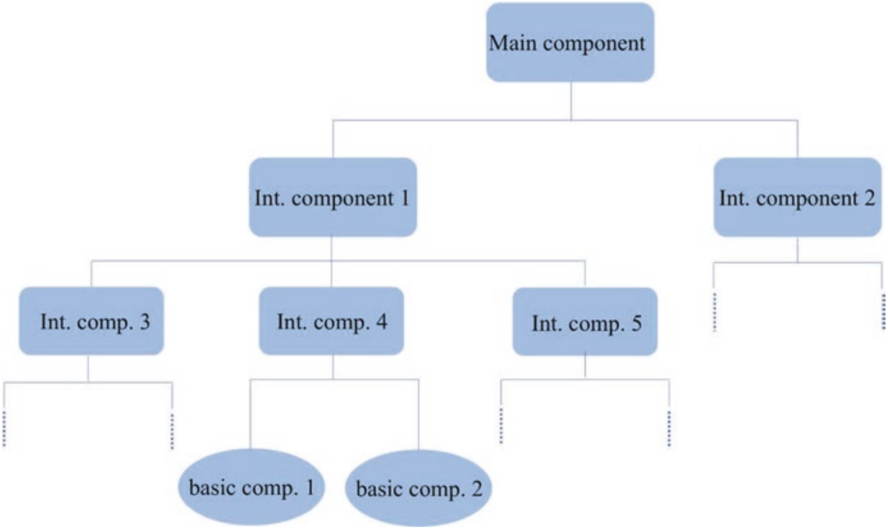

Fig. 1.7 Dependence tree diagram and different types of components

where $I_{i,N}$ is the normalized score of indicator i $(0 \leq I_{i,N} \leq)$, I_i is the total indicator score obtained from Sendai framework $(0 \leq I_i \leq 5)$, and $I_{i,\max}$ is the maximum score that can be reached by an indicator I $(I_{i,\max} = 5)$.

There are two limitations to the proposed method: (1) the DTA results are dependent on the tree structure, which defines the links between the different indicators; (2) only numerical indicators can be combined (e.g., Boolean indicators cannot be implemented in this method).

5.2 *Spider Plot Weighted Area Analysis (SPA)*

Another option for weighting the Sendai Framework indicators is the Spider Plot Weighted Area, which represents the indicators with a spider plot. Resilience is simply the enclosed area obtained by connecting the indicators and then normalized to the total area of the polygon (Fig. 1.8). Resilience is mathematically calculated as:

$$R = \frac{A}{A_{\max}} \tag{1.11}$$

where R is the resilience, A is the total area of the polygon, and $A_{\max}$ is the maximum area that can be reached if all indicators are equal to 5.

Different indicator arrangements were attempted, and the area of each arrangement was computed using MATLAB to show that the value of the area inside the enclosed shape is not very sensitive to the indicators' arrangement order (Kammouh,

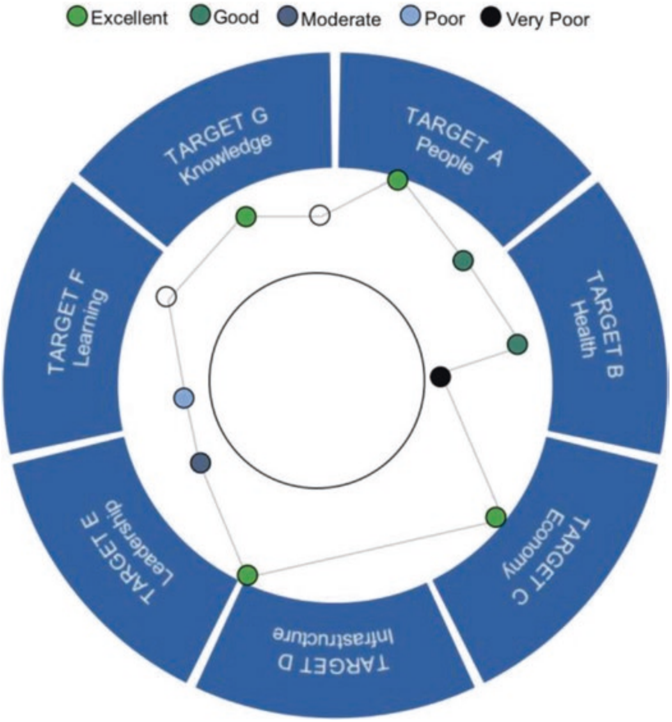

Fig. 1.8 Spider plot representation of the Sendai indicators

Cardoni, et al., 2018; Kammouh & Cimellaro, 2018; Kammouh, Cimellaro, & Mahin, 2018; Kammouh, Dervishaj, & Cimellaro, 2018; Kammouh, Silvestri, et al., 2018; MathWorks, 2005).

6 Conclusion

This chapter introduces a new analytical method for quantifying the resilience and resilience-based risk of countries. The resilience-based risk is defined as the probability of being below a certain resilience level and is calculated by combining resilience, exposure, and hazard. In this chapter, the resilience index is evaluated by using the results of Sendai Framework for Disaster Risk Reduction (SFDRR), which ranks the countries based on 33 indicators. Despite the Hyogo Framework for Action is a widely accepted method in evaluating the community risk reduction, the Sendai Framework presents a higher level of complexity due to its multiple layers structure.

Like in the HFA, not all the indicators contribute in the same way towards the resilience output. Therefore, the indicators of SFDRR are weighted and combined using two different methods to determine the resilience index, the Dependence Tree

Analysis (DTA) and the Spider Plot Analysis (SPA). The DTA method identifies the correlation between resilience and its indicators in a quantitative way. The SPA, on the other hand, is a geometrical method in which the indicators are plotted on the spider chart's axes. The resilience is evaluated as a normalized value of the area obtained by connecting the adjacent indicators' score. The weights for targets E and G in the Sendai framework don't need to be computed since they are already weighted in the Sendai Framework result. The developed framework has not been applied to any case study since data from the countries are currently being collected by the UN and they are not yet available.

In conclusion, following the methodology described above, each country would be able to quantify its resilience-based risk to be prepared for future disasters and to mitigate their impact. This can be done by analyzing the hazards from the hazard map, the exposure from the WWR, and the resilience parameter through the Sendai Framework.

The quantitative approach introduced in this chapter allows to have a proper estimation of how long it would take a system or a community to restore its functionality to its original state. However, the proposed approach is general. Future work will be oriented towards the application of the presented methodology using reliable data as soon as they are available to determine the resilience index of communities.

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