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IoT for Environmental Management and Security Governance: An Integrated Project in Taiwan

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Abstract: Taiwan is in a hazard-exposed area where people often suffer through typhoons, earthquakes, and landslides, and must face the challenges of environmental and climate changes in ongoing and future developments. Taiwan has implemented an integrated and interdisciplinary project, which is titled Civil IoT Taiwan, for better disaster risk management and risk communication with all stakeholders by cooperating closely with authorities, scientists, and industry. The purposes of this project are to raise public risk awareness to reduce disaster damage and loss and sustainably increase the social, economic, and environmental impacts. For measuring the social impacts of the Civil IoT Taiwan, the social return on investment (SROI) is an evaluation tool to demonstrate the outcomes and impacts of Civil IoT Taiwan to measure its social effects. The SROI ratio of this project is 1.12. Civil IoT Taiwan has just implemented the first development stage in establishing infrastructure for monitoring and sensing; thus, the significant changes and impacts on society, economics, and the environment will be evaluated in the next phase. This ongoing project will also involve more stakeholders for more sustainable and resilient environmental governance in future development.

Keywords: Internet of Things (IoT); social return on investment (SROI); Civil IoT Taiwan; security governance; environmental sustainability

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1. Introduction

Taiwan is located in a hazard-prone area, where it suffers frequent and multiple hazards affecting large areas of the population and land [1–3]. People in Taiwan face the threats of earthquakes, typhoons, landslides, and debris flows (around 73.1%) [4]. According to the statistics published by the National Fire Agency, natural hazards have occurred more than 300 times in Taiwan between 1958 and 2015. Although earthquakes covered less than 1% of all hazard events, they often cause severe damage and considerable losses to infrastructure and buildings [2]. The most devastating natural hazard over the past decades was the Chi-Chi Earthquake in September 1999 (local magnitude, M_L = 7.3). More than 2500 people were killed, around 11,305 were injured, and US$10.7 billion in damage was recorded. The destruction of the infrastructure and lifeline system greatly affected livelihoods and economic activity [4]. Another deadly typhoon in recorded history was Typhoon Morakot, which hit the mountain areas of southeastern Taiwan in 2009. Around 700 people killed or missing, and the catastrophic damage cost roughly US$3.3 billion.

Different projects have been launched based on the Sendai framework for disaster risk reduction to reduce disaster loss and damage to the critical infrastructure and raise public awareness of all stakeholders in Taiwan [2]. Moreover, the review reports of severe disasters emphasized that disaster risk management and risk communication with scientific and technical knowledge are critical to raise public awareness of disaster prevention and take action to avoid damage and consequential costs.

It is critical to communicate effectively with people regarding different types and effects of risk they face and the corresponding actions that should be taken according to the given information. Moreover, governments have a responsibility to provide information to the public about hazards and suggest corresponding actions for different scenarios to reduce disaster damage [5]. It is essential to prepare annual programs and project budgets in disaster management to prevent economic risk and the loss of livelihoods from natural hazards.

With the development of the Internet of things (IoT) and artificial intelligence (AI) technology governments, scientists, and private sectors in Taiwan have made efforts toward solution-based programs for monitoring, evaluating, and warning systems for disaster management. A solution-based project called "Civil IoT Taiwan" started in 2017. Civil IoT Taiwan combines big data, IoT, and AI-focused programs to promote smart governance in four key areas: earthquakes, water resources, air quality, and disaster prevention. It is assumed to boost economic development and cooperation in the disaster prevention industry. The main goal of this project is to develop a better relationship with nature to reduce the effects and risks of natural hazards [6,7].

Risk communication plays a crucial role in disaster risk management by engaging people on critical issues, disseminating information, creating platforms to share ideas, and hosting discussions on governance [5]. For better risk communication with all stakeholders (mainly decision-makers and the public), two platforms for emergency operations and interactive information delivery play critical roles in Civil IoT Taiwan for decision-making and risk management. This paper focuses on the practical progress of Civil IoT Taiwan and reviews the reports of the first phase of this medium-term development plan for confirming the quality of the achievements. However, it is difficult to measure the social value and environmental impacts for this kind of cross-sectoral projects. The SROI provides a perspective on assessing the social, economic, and environmental impacts with cost-benefit analysis, and a concept of displaying changes from the evaluation results.

2. Application of the IoT in Disaster Risk Management

2.1. Trends in IoT Development

2.1.1. Definition and Development of the IoT

The IoT was proposed in "The Road Ahead" by Bill Gates in 1995 [8] and has been in use since 1999 [9]. It defines the evolution of the internet where computing devices (including computers, laptops, tablets, and mobile phones) can be embedded in everyday objects to send and receive data [9,10]. With the development of the Internet and computer science, the IoT is not just a network of computing devises but has also evolved into vehicles, home appliances, toys, cameras, medical instruments, buildings, and industrial systems for sharing information and interacting with each other. Today, the IoT can be grouped into three categories: (1) people to people, (2) people to devices, and (3) devices to devices (Figure 1) [10,11].

2.1.2. Application of the IoT in the Environmental Field

The IoT has become one of the most critical technologies of the 21st century and can connect and interact with many everyday objects. Nevertheless, with the development of some technologies, i.e., access to low-cost sensor technology, storage on cloud computing platforms, machine learning and analytics, and conversational AI, the IoT can be applied for collecting big data and calculating results to provide relevant information about the operation, performance, and environmental conditions that people want to monitor and control at a distance [12]. With monitoring, measurement, data collection, and analysis, the IoT benefits environmental sustainability, such as resource management, ecosystem preservation, energy efficiency, and security governance. In addition, IoT-based environmental monitoring provides information for improving life quality, preventing natural disaster risks, facilitating disaster risk communication, and adjusting water resource management. Today, IoT is changing aspects of our everyday lives, and the data it collects from different sensor areas are analyzed and applied in practice smartly and conveniently to increase environmental sustainability, social security, and economic efficiency.

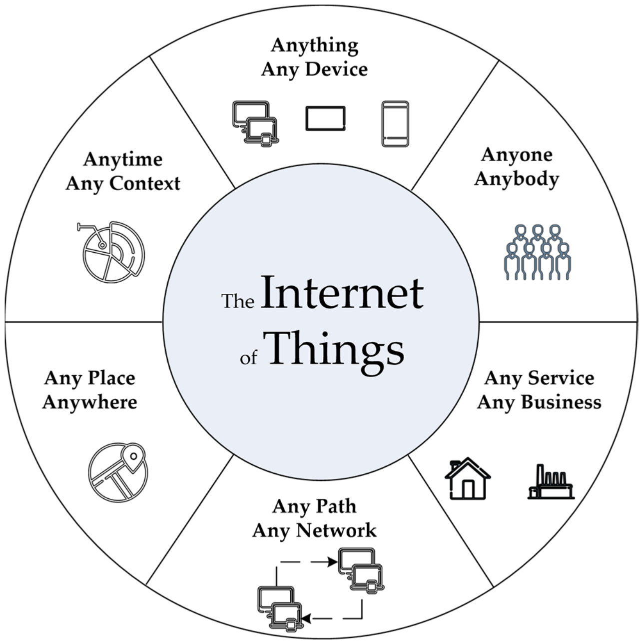


Figure 1. Internet of Things. Adapted from [10].

2.2. Disaster Risk Management and Security Governance

2.2.1. Disaster Risk Management

Disaster management aims to reduce or avoid potential loss of properties, livelihoods, and lives from hazards. Preventing future emergencies and minimizing their effects before a major disaster is essential to provide prompt and appropriate assistance to victims and achieve rapid, effective recovery. The preparedness of taking actions ahead and being ready for an emergency is part of a crucial phase for disaster risk management. The more people are prepared for risk management, the less they must deal with for crisis management.

The Sendai Framework for Disaster Risk Reduction 2015–2030 outlines four priorities for action to prevent disaster risks in the early stages of disaster management: (1) understanding disaster risk, (2) strengthening disaster risk governance to manage disaster risk, (3) investing in disaster reduction for resilience, and (4) enhancing disaster preparedness for effective response to "build back better" in recovery, rehabilitation, and reconstruction [13]. The priority actions emphasize that an interactive platform for risk governance is better than top-down management. An efficient risk management plan relies on risk communication in the preparedness phase (Figure 2).

2.2.2. Risk Communication and Security Governance

Risk communication refers to information exchange about the risks caused by hazards, and it is an essential component of disaster risk management. Risk communication is a dynamic and interactive process involving exchanges between all stakeholders (including authorities, private sectors, and citizens) [14,15]. Hence, hazard identification, risk assessment, decision-making, and implementation for the preparedness phase shape people's perceptions of risk and influence the response during an emergency (Figure 3).

Governments are considered responsible for the preparedness of disaster risk management, and they focus on avoiding or reducing disaster risks that may develop in the future. It is also crucial to strengthen individuals' and societies' social and economic resilience in the face of disaster risk that cannot be effectively reduced [16]. However, raising public awareness of disaster risk and life-saving responses plays a vital role in security governance. Better risk assessment and communication are important to interact with the public and help reduce the loss and increase resilience. However, local communities generally lack the tools and skills to conduct scientific risk assessments and understand the underlying risk in their localities [15]. Therefore, an integrated platform with information for emergency operations is worthwhile for risk communication and decision-making.

Figure 2. Four phases of disaster management.

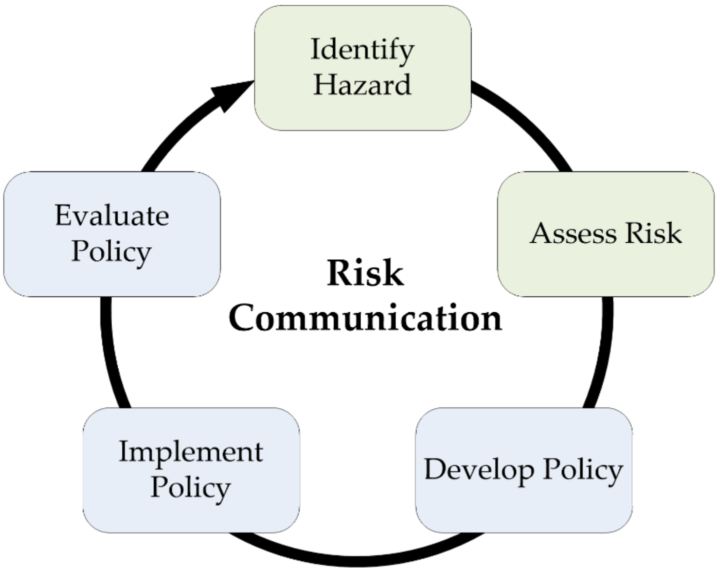


Figure 3. Role of risk communication in the risk management cycle. Adapted from [14].

2.3. Civil IoT Taiwan

Civil IoT Taiwan is a solution-based interagency plan for dealing with public interests and public policy issues (i.e., air quality, earthquakes, water resource management and disaster management; Table 1). It is also a public-private partnership (PPP) program for smart environmental governance to arrange public and private sectors from a long-term perspective in cooperation with authorities, scientists, and industry. Data collection by monitoring (Location Aware Sensing System or LASS), data analysis, and data application are critical duties in the decision-making process [7]. With the technologies of IoT and AI, the targets of Civil IoT Taiwan are as follows:

1. establish IoT for the smart monitoring of environmental quality,
2. improve the earthquake early warning (EEW) system for reducing loss,

3. integrate the platform for disaster management (Integrated Platform on Information and Intelligence of Disaster), and
4. improve the IoT for water resource management.

Table 1. Main functions of each subproject of Civil IoT Taiwan.

Subprojects [a]	Functions
Air quality	A. Develop air quality sensors B. Deploy air quality sensors across the island C. Auxiliary environmental inspection D. Prompt private-sector development of air quality sensing
Earthquake	A. Deliver a submarine cable seismic and tsunami observation system B. Develop a hybrid earthquake early warning platform C. Encourage private-sector applications and developments in disaster preparedness
Water Management	A. Establish a common application platform for disaster prevention B. Establish a public alert open data platform C. Provide real-time and historical Civil IoT sensing data by the Open Geospatial Consortium SensorThings Application programming interface
Disaster prevention and response	A. Develop and deploy a multiple water source monitoring system B. Apply an irrigation water allocation dynamic analysis management platform C. Provide flood warnings D. Develop a value-added application of the sewerage system management cloud

[a] [7].

Two platforms for collecting, analyzing, and storing data from monitoring, open data, IoT, and fieldwork play important roles in disaster risk management and risk communication (Figure 4). The first phase of this medium term plan was established and implemented from 2017 to 2020.

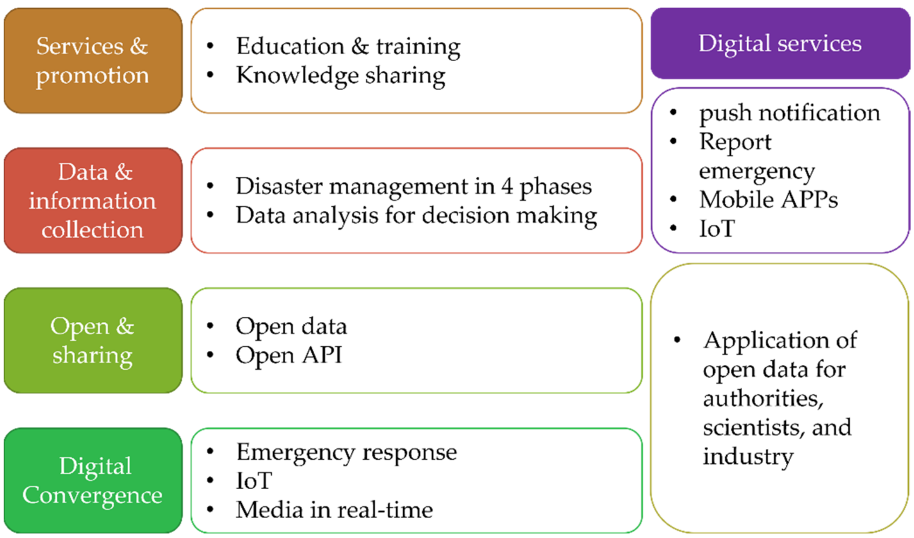


Figure 4. Framework for disaster risk management. Adapted from [7], p.111.

3. Methods

3.1. Research Scope

There are two key performance indicators of Civil IoT Taiwan: reducing the loss of properties and lives and strengthening risk communication. This public-private investment program attracts local and international participants and may influence people in disaster risk governance. This paper focuses on the achievements of key performance indicators and the cost-benefit analysis of investments using SROI to understand the effectiveness and influence of Civil IoT Taiwan. The essential data were collected and calculated from official annual reports for disaster risk reduction by governments from 2016 to 2020 to calculate the SROI ratio. More details about the process are provided in the next section.

3.2. Social Return on Investment

The principles and model of the SROI area illustrate the social value of increasing social equality, environmental sustainability, and wellbeing. The SROI demonstrates the cost-benefit analysis of investments and evaluates the underlying impacts and values on society and sustainability. The results provide qualitative and quantitative information for decision-makers to adjust the upcoming projects and engage a broad range of stakeholders. The SROI is applied and set out in the following seven principles and six stages: (1) involve stakeholders, (2) understand what changes, (3) value aspects that matter, (4) only include what is material, (5) do not overclaim, (6) be transparent, and (7) verify the result (Figure 5) [17].

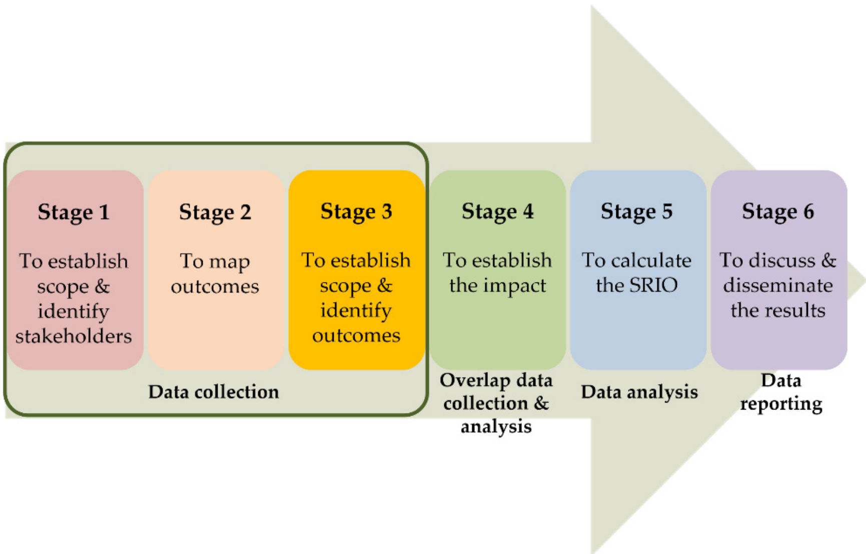


Figure 5. Stages of the SROI. Adapted from [17].

The four key elements to evaluate the SROI are inputs, outputs, outcomes, and impacts. The inputs are costs invested in achieving the project purposes, and the outputs are the direct results of the project to demonstrate achievement. Moreover, the changes that happen in stakeholders affected by the project can be evaluated as outcomes. The effects include the added value created through project support and outcomes. The social, environmental, and economic values created through this project are understood based on the impacts [18]. The SROI ratio is calculated as follows:

$$SROI = \frac{(Net\ Present\ Value\ of\ Impact)}{(Net\ Present\ Value\ of\ Investment)}$$

4. Results

4.1. Assumptions, Data Collection, and Outcomes of Civil IoT Taiwan

The first phase of Civil IoT Taiwan aimed to establish a better PPP for disaster risk management, reducing disaster damage and loss, and strengthening risk communication. Building a disaster early warning system and establishing integrated platforms for risk communication are the primary aims of this project. Table 2 lists the critical questions of establishing an SROI model for this project to identify the scope and collect appropriate data. The first step is to identify stakeholders involved and affected through Civil IoT Taiwan. Therefore, the project stakeholders are grouped as authorities (governments), the public, and relevant industries of disaster management. In the second step, the assumptions of outcomes present ways to reduce disaster damage and loss due to better disaster preparedness and risk communication. The third step presents the outcomes and evaluates all outcomes in currency. However, some factors (i.e., deadweight, displacement, attribution, and drop-off) should be deducted due to double counting or replacement, and the none-activities benefits should not be counted as outcomes.

Table 2. Key questions of establishing Social Return on Investment model for risk management.

Questions [a]	Description	Data Collection for SROI
Who changes? (Identify stakeholders)	Involving all people, organizations, and environments significantly affected	1. Authorities (decision-makers) 2. Public 3. Industry
How do they change? (Understand what changes)	Focusing on the important changes both positive and negative	1. Reduced disaster damage/loss 2. Disaster preparedness and mitigation 3. Risk communication
How do you know? (Value the things that matter)	Gathering evidence to go beyond individual opinion. Rating the important outcomes by valuing economic, social, and environmental benefits and costs	1. Infrastructure and platform for risk management 2. Data collection and analysis 3. Information delivery services 4. Additional industrial investments
How much is you?	Accounting for other influences that might have changed the situation for the better or worse	1. Thought changed 2. Preparedness 3. Reduced loss and cost saved
How important are the changes? (Verify the result)	Understanding the relative value of the outcomes to all affected stakeholders	1. Loss reduced 2. Cost saved 3. Lives saved

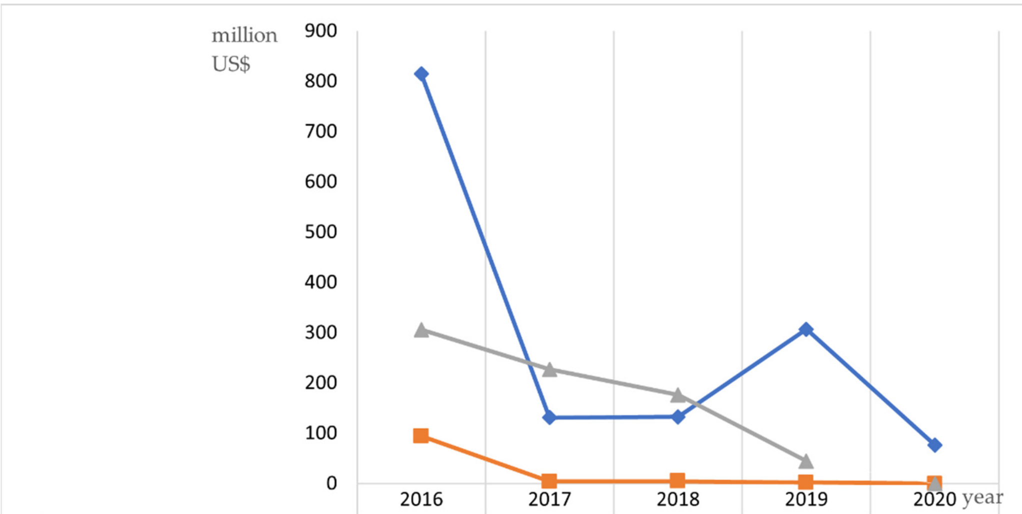
[a] adapted from [17].

The effects on natural hazards over the last few years are listed in Table 3 and illustrated as Figure 6 to demonstrate the outcomes of reducing disaster damage and loss. No direct evidence indicates that Civil IoT Taiwan helped reduce the numbers of deaths and rescued victims because hazard events have had different intensities and frequencies over the years and have affected various groups in diverse areas. However, as the official reports (*White Paper on Disaster Management* and *Statistics for natural disaster losses*) demonstrate, the disaster damage in agriculture and infrastructure has been significantly reduced in recent years. More evidence of the changes for different stakeholders should be evaluated using a questionnaire or focus interviews.

Table 3. Disaster damage and loss due to natural hazards.

Year	Disaster Events [a]	Person					House/Building	
		Dead	Missing	Heavily Wounded	Lightly Wounded	Rescued Victims	All Destruction	Half Destruction
2016	1 earthquake, 7 flood events, 5 typhoons	130	0	88	1515	2209	142	175
2017	1 earthquake, 2 droughts, 4 flood events, 4 typhoons	5	2	10	138	485	0	7
2018	1 earthquake, 1 drought, 9 flood events, 2 typhoons	24	1	22	326	1956	4	0
2019	2 earthquakes, 1 drought, 11 flood events, 3 typhoons	5	1	1	71	114	0	4
2020	3 droughts, 6 flood events, 5 typhoons	1	1	0	5	3	0	0

[a] Duration: 2016 to 2020 [13,19–22].



	2016	2017	2018	2019	2020
disaster damage: Agriculture	815.1	131.03	132.24	306.7	76.54
disaster damage: others	94.12	4.06	4.41	2	0.0035
recovery of infrastructure	305.67	226.92	175.95	44.55	NA

Figure 6. Disaster damage and loss due to natural hazards in Taiwan (2016–2020) [13,19–21,23–27].

To compare with the previous year (2016), the disaster damage and loss due to natural hazards from 2017 to 2020 were calculated, and the primary effect of the damage loss of agriculture was US$646.51 (the blue line in Figure 6), and other effect of disaster damage was US$10.47 (the orange line in Figure 6). The reconstruction costs of infrastructure were US$447.42 (the blue line in Figure 6). To compare with the annual budget for the reserve fund for disaster response, the saved reserve funds totaled US$191.57 from 2017 to 2020.

4.2. SROI Evaluation and Analysis of Civil IoT Taiwan

According to the assumptions and data collection, Table 4 lists the investments from all stakeholders of this PPP project. The investments in Civil IoT Taiwan are grouped into three dimensions: (1) infrastructure for early warning and monitoring, (2) platform for integrated disaster preparedness and mitigation, and (3) water management. The main investments went to infrastructure for early warning and monitoring, and more than 77% of the investments relied on annual budgets of governments. The private sector followed the policies and strategies by investing in these three types of industries. However, the values invested by public are not easy to value in currency; that will be improved in the second phase of IoT Taiwan. The outputs of Civil IoT Taiwan then display in different aspects (social, economic, and environmental) in Table 5. The Civil IoT Taiwan is not just a project to establish a safer and resilient environment by setting up an EEW system and interactive platforms for disaster preparedness and communication. It also provided job opportunities in these industrial areas. Moreover, the education videos and training courses can help with raising risk awareness and taking appropriate actions for disaster risk management.

Table 4. Investments (inputs) from all stakeholders of Civil IoT Taiwan.

Stakeholders	Items	Values [a]
Authorities	Infrastructure for early warning and monitoring	93.05
	Platform for integrated disaster preparedness and mitigation	50.35
	Water management	29.25
Industry of disaster prevention	Infrastructure for early warning and monitoring	32.66
	Platform for integrated disaster preparedness and mitigation	13.93
	Water management	3.77
Public	Time and personal equipment (e.g., PC, mobile phones, etc.) to obtain information	0 [b]
	Sum	223.01

[a] Unit: million US$, Duration: 2017 to 2020 [7,28]. [b] Hard to value in currency.

Table 5. Social, economic, and environmental outputs of Civil IoT Taiwan.

Aspects	Social	Economic	Environmental
Outputs [a]	1. Shortened EEW of earthquakes by 20 s 2. 20,000 views of environmental education videos 3. Training for decision-makers 36 times with 1451 people 4. Pushing notifications by 570,000 times with 2 billion datasets and 260,000 interface data (2017 to 2020)	1. 14 industrial investments 2. provide vacancies	1. Setting monitoring, evaluation, and storage systems in 263 districts, 111 industrial parks, and platforms 2. 97 EEW stations 3. 23 early warning information items

[a] Duration: 2017 to 2020 [28,29]. EEW: earthquake early warning.

The progress and performance report for 2020 for Civil IoT Taiwan lists the benefits and influence on social, economic, and environmental factors for this first stage of the medium-term development plan. The main impact amount present in the social aspect by US$210.34, which provides evidence of the preparedness of disaster management on reducing disaster damage and loss and the saved amount of the reserve fund. Civil IoT Taiwan also supports businesses in disaster prevention to increase orders from domestic and international demands by US$20.67. As the annual reports display that the saved amount of reserve fund in the environmental aspect is US$2.99.

Disaster risk management has been identified as a critical issue and set as principal duties and responsibilities regarding investments in infrastructure. Besides Civil IoT Taiwan, many medium-term development plans have been implemented for risk management over the past decades. Therefore, similar attributions should be deducted from the SROI analysis. To combine with the data display in Table 4 (investments by governments and private sectors as inputs of SRIO ratio) and Table 6 (impacts on three different aspects), Table 7 presents the final SROI ratio of the Civil IoT Taiwan by 1.12.

Table 6. Outcome and impacts of Civil IoT Taiwan.

Outcomes	Impacts	Amount [a]
Social aspect: 210.34		
Shortened EEW of earthquakes by 20 s	Reduced disaster damage and loss and saved lives	18.67
20,000 views of environmental education videos	Reduced disaster damage and loss risk awareness	N/A
Training for decision-makers 36 times with 1451 people	Reduced disaster damage and loss	N/A
Pushing notification 570,000 times	Saved amount of reserve fund	191.57
Economic aspect: 20.67		
Industrial investments	Increased orders	18.67
Provide job opportunities	Increased capacities	2
Environmental aspect: 2.99		
Setting monitoring, evaluation, and storage system in 263 districts, 111 industrial parks, and platforms	Reduced disaster damage and loss Saved amount of reserve fund	2.99
23 early warning information items from by 97 EEW stations	Reduced disaster damage and losses	N/A
Sum (not discounted)		234

[a] Unit: million US$, Duration: 2017 to 2020 [21,28].

Table 7. SROI Ratio of the Civil IoT Taiwan.

Items	Amount	Items	Amount
Input		Attribution	
Infrastructure for early warning and monitoring	125.71	Disaster Prevention and Protection Project	13.30
Platform for integrated disaster preparedness and mitigation	64.27	Impact	
		Social aspect	210.34
		Economic aspect	20.67
Water management	33.02	Environmental aspect	2.99
Sum (million US$)	223.01	Sum (million US$)	234
SROI Ratio [a] = 234/(223.01−13.3) = 1.12			

[a] Duration: 2017 to 2020 [28].

5. Discussion

5.1. Limitations of SROI Analysis

Civil IoT Taiwan is an integrated and interdisciplinary project with leading trending technologies for environmental management and disaster risk governance. It can establish a safer and more resilient environment for disaster risk management by establishing monitoring and early warning systems, and it is essential to raise the risk awareness of the public. Interactive platforms established in Civil IoT Taiwan play essential roles in delivering and collecting information in real time during disasters in the region. This project is presumed to have a high influence on social, economic, and environmental aspects.

The SROI ratio is a good methodology to analyze the investment benefits with empirical evidence. Though the results of the SROI ratio is positive for the social impact aspect, some non-financial impacts quantification is not easily calculated in currency. Moreover, the first stage of Civil IoT Taiwan implements a basic infrastructure, and some social and economic effects may appear later. In addition to statistics and annual reports, some opinions on the social impacts should be gathered from stakeholders through a questionnaire or focus interviews. The outcomes and impacts of Civil IoT Taiwan should be higher than those in progress and performance reports.

5.2. Suggestions for the Second Phase of Civil IoT Taiwan

The SROI analysis is well designed to measure the efficiency of project achievements using social, economic, and environmental values and is an appropriate tool to forecast and finely adjust the duties of subprojects in achieving a major project. The second phase of Civil IoT Taiwan started in 2021, and the impacts should be more significant and appropriate when evaluated using an SROI analysis, that can be designed and demonstrated on the interactive platform (Integrated Platform on Information and Intelligence of Disaster) to collect feedback from relevant stakeholders. It is worth to explore and assess social and environmental impacts with SROI tool, as better understanding of risk management process, and more comprehensive information for preparation, plans, and actions for decision-making. The approach will eventually lead to better engagement with all stakeholders for disaster risk management.

6. Conclusions

Most projects coping with disaster risks often focus on the stages of response and recovery in Taiwan. However, public risk awareness and self-preparedness for disaster risk prevention are essential to reduce damage and loss. Civil IoT Taiwan is an integrated project to establish a critical infrastructure and raise public risk awareness of the preparedness stage of disaster management. After the first phase of building the foundation for monitoring and sensing, it is essential to widely promote platforms aligned with the targets and priority actions of the Sendai Framework for Disaster Risk Reduction to the public and will also contribute to engaging with relevant stakeholders sustainably. Moreover, Civil IoT Taiwan encourage PPP for disaster governance, a positive result of SROI may influence the decision-makers, scientists, and private sectors to cooperate closely and implement risk analyses for disaster management.

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Abbreviations

AI	Artificial Intelligence
EEW	Earthquake early-warning
IoT	Internet of Things
PPP	Public-private partnership
SROI	Social return on investment

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