Technology And Investment Evaluation In Earthquake Early Warning System In Indonesia: Benefit-Cost Approach

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ABSTRACT

Indonesia is particularly vulnerable to natural disasters, especially earthquakes, due to its location at the intersection of four tectonic plates. This geographical setting, combined with human activities such as groundwater extraction and fossil fuel exploitation, exacerbates the risk of seismic events. Earthquakes result in significant economic losses, disrupt communities, and cause physical and psychological harm to victims. An effective early warning system (EWS) is essential for minimizing these impacts by providing timely alerts before seismic shocks occur. Research indicates that accurate and prompt warnings can significantly reduce casualties and property damage by enabling individuals to take protective actions. However, the success of EWS depends on the reliability of information and community responsiveness. This study aims to analyze the costs and benefits of implementing an earthquake early warning system in Cianjur Regency, a seismically active area due to the Cimandiri fault. By analyzing potential reductions in economic losses, social impacts, fatalities, and environmental degradation attributable to an effective EWS, this research underscores the imperative for robust disaster risk reduction strategies in Indonesia's earthquake-prone regions.

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INTRODUCTION

Indonesia is a country that is vulnerable to natural disasters, including earthquakes. In the BNPB report[1]. Moreover, research Socquet (2019) shows that vulnerability is caused by the geographical conditions of Indonesia, where Indonesia is located at the meeting of four tectonic plates: the Asian Continental Plate, the Australian Continent, the Indian Ocean Plate, and the Pacific Ocean. These conditions cause Indonesia to have a tropical climate with two seasons, namely hot and rainy, which can cause extreme weather, temperature, and wind direction changes. In addition to being caused by Indonesia's geography, disasters are also caused by increased human activities that pay little attention to the environment. These activities include activities of the surrounding community, including excavation and extraction of groundwater, coal, oil, and natural gas (Foulger et al., 2018).

Natural disasters, especially earthquakes, cause many losses. Earthquakes cause significant economic losses, including disruption of housing and business in developing and developed countries (Rashid & Ahmad, 2017). The losses were not only economic but also caused many deaths, injuries, and psychological (trauma) victims (Amri et al., 2016; Nurhadi et al., 2021). In addition, disasters indirectly cause a decline in several sectors' community welfare and production assets (Nurhadi et al., 2021).

An early warning system can minimize losses due to natural disasters. Meteorology, Climatology, and Geophysics Agency (2012) define early warning as a combination of technological and community capabilities to follow up on the results of early warnings. According to Strauss (2016), an early earthquake warning is an effort to detect earthquakes quickly by warning people in danger. The warning occurs within seconds to minutes before a strong shock comes.

Furthermore, Bouta et al. (2020) argue that the earthquake early warning system helps reduce damage and prevent victims from a devastating earthquake with early notification. Early warning is part of disaster risk reduction through technically accurate warnings and a good understanding of the risks of a warning so that a relationship is established between the provider of early warning system tools and warning users. If one of the components cannot be met, the early warning system will not be optimal for use. This tool can reduce the impact of earthquakes felt by the community. The early warning system requires the ability of information recipients to process information so that recipients can respond to information quickly (Allen & Melgar, 2019). During the time between the warning and the occurrence of the earthquake, people can use the time to save valuables and escape as soon as possible (Strauss, 2016; Allen & Melgar, 2019).

The development of earthquake early warning technology needs to consider investment and profit values so that its existence can provide benefits. Bouta et al. (2020) argued that early warnings issued are only sometimes correct. When the early warning is wrong, the social costs that will be incurred will be significant. Therefore, according to (Jin and Lin, 2011) and (Bouta et al., 2020), the development of the warning device must be precise and accurate, and how the recipient of the information must process the information and take further action. In addition, the technology must also be routinely maintained so that its use remains optimal. Therefore, the tsunami early warning system

[1]National Disaster Management Agency (BNPB), downloaded onhttps://bnpb.go.id/potensi-ancaman-bencana, accessed June 12, 2022

will provide benefits if the construction costs and operational costs are lower than the reduction in losses that can be avoided.

Jin & Lin's (2011) research analyzed the value of the benefits of the existence of an earthquake detection system from economic activities. Suppose the system is assumed to be able to reduce damage by 45% of regional economic output, and the possibility of an earthquake is 1/100 (it only occurs once in 100 years). In that case, the expected benefit of the early warning system is $ 90 million per year for the entire region and $ 4 million per independent country. However, if the reduction in losses by 7% of economic output and tsunamis occur every 500 years, the estimated annual benefits are reduced to $ 2.8 and $ 1.4 million.

Another study Fakhruddin & Schick (2019) calculated the benefits of early warning devices in Samoa. The benefits of early warning of natural disasters can be divided into direct and indirect. Direct benefits include damage that all residents can avoid because early warning of natural disasters accurately provides disaster information, and residents can respond to the disaster information. At the same time, indirect benefits such as aid and rehabilitation costs can be avoided when a natural disaster occurs.

The benefit of early warning is the difference between the potential damage reduction due to early warning and the cost/investment to provide early warning services. Furthermore, the potential damage reduction value due to early warning is the difference between the loss due to a disaster without early warning and the reduction in losses that may arise after early warning. The benefit value will be greater if the damage reduction exceeds the investment cost for providing early warning equipment.

Then, Fakhruddin and Schick (2019) calculated the tsunami's early warning device's benefit cost for 10 years. The total cost for 10 years was USD 5.12 million with a fixed cost of USD 1.92 million and a variable cost of USD 0.32 million/year, so the variable cost for 10 years was USD 3.2 million. The total benefit value for 10 years, with 2 disaster events, was assumed to be USD 15.20 million. Therefore, every USD 1 invested in a natural disaster early warning device in Samoa generates a profit of USD 6.0.

Bouta A. et al. (2020) analyzed the early warning system in Washington by comparing losses without and with early warning devices. The initial capital investment was $15.2 million, with annual maintenance and operations costs of $4.7 million for the first three years, followed by $2.3 million annually after that. The device is assumed to be used for 50 years. If the device can play an active role, the device can provide benefits of $ 6,478,250. The B/C ratio calculation is calculated based on the parameters tested, and the estimated net present benefit is divided by the net present cost. The value ranges from 1.86 to 7.02.

This study aims to analyze the costs and benefits/losses that can be avoided if the early warning system for disasters accurately provides information on earthquake events in Cianjur Regency in 2022. The Cianjur Regency area is earthquake-prone because Cianjur Regency is crossed by the Cimandiri fault in the Rajamandala segment, which has a left-lateral strike-slip fault mechanism (Supendi et al., 2022). When Cianjur Regency has an earthquake early warning system, economic losses, social losses, deaths, community trauma, and environmental losses such as land, water, and air pollution can be avoided.

METHODOLOGY

The method used is an exploratory study based on primary and secondary data. Primary data is used through in-depth interviews with the National Disaster Management Agency/ The National Agency for Disaster Countermeasure (BNPB) and the Cianjur community. In addition to primary data, secondary data used in this study comes from the report of The National Agency for Disaster Countermeasure (damage report due to the Cianjur earthquake) and a literature study to find out previous studies related to the benefits and costs of having an early warning system for natural disasters.

This study's early warning system techno-economic analysis follows research by Fakhruddin & Schick (2019) in calculating the cost-benefit value (benefit-cost analysis). The calculation of the cost of early warning devices consists of 3 components, namely total cost (TC), fixed cost (FC), and variable cost (VC), which can be seen in the equation below:

$$\text{Total cost} = \text{Fixed Cost} + \text{Variable Cost} \quad \text{....(1)}$$

Information :

- Fixed cost consist of 3 components:
  - SC = scientific component costs: required to produce forecast information
  - IC = Institutional component costs: This refers to training and capacity-building costs for using forecast information, especially to facilitate its use at lower levels.
  - CC = Community component: input costs at the community level to enable them to adopt forecast information and respond appropriately.
- Variable cost: Annual variable costs for system maintenance, institutional development, and others.

In addition to costs, early warning devices for natural disasters can provide benefits if the potential for reducing losses is higher than the total cost of providing the device. The equation for the value of benefits can be seen from the equation below:

$$\text{Benefits of early warning: } A - B - C \quad \text{...(2)}$$

Information :

A : Losses disasters without early warning
B : Reduction of losses that may arise after taking action following early warnings
A – B : Potential damage reduction due to early warning
C : Cost/investment to provide early warning services

The benefit of early warning is the difference between the potential damage reduction due to early warning and the cost/investment to provide early warning services. Furthermore, the potential damage reduction value due to early warning is the difference between the loss due to a disaster without early warning and the reduction in losses that may arise after early warning. The benefit value will be greater if the damage reduction exceeds the investment cost for providing early warning equipment.

RESULTS AND DISCUSSION

A. Earthquake in Cianjur Regency, West Java

Cianjur is a region that is quite vulnerable to disasters because Cianjur City is a wavy plain, and wavy hills are too steep. In addition, Cianjur comprises quaternary deposits in the form of young volcanic debris rocks (breccia, volcano, lava tuff) and river alluvial.

Cianjur, West Java earthquake occured on November 21, 2022, with a magnitude of 5.6 Mw. The earthquake occurred at a depth of 10 km centered on land at coordinates 107.05 East Longitude and 6.84 South Latitude, approximately 9.65 km southwest of Cianjur City or 16.8 km northeast of Sukabumi City[2]. The earthquake was felt as far as Garut, Sukabumi, Cimahi, Lembang, Bandung City, Rangkasbitung, Bogor, Depok, Jakarta, and Tangerang. According to Supendi et al. (2022), the earthquake originated from a fault with a left-slip fault mechanism in the southwest-east direction parallel to the Cimandiri fault, Rajamandala segment.

The earthquake killed 334 people, left 13 missing, and seriously injured 593. It also caused severe damage to settlements, with 12,956 units severely damaged, 15,196 moderately damaged, and 25,256 slightly damaged. Damage also occurred to public facilities, with 540 school units, 272 places of worship, and 18 health facilities damaged (Muhari, 2022).

B. Simulation of cost-benefit estimates for the Cianjur Regency Earthquake

This study analyzes the cost and benefit values of the earthquake in Cianjur in 2022. Researchers conducted a cost analysis by calculating investment costs and operational costs. Meanwhile, the value of the benefits could be obtained if Cianjur had an early warning system at that time that could minimize losses. The early warning system can provide benefits when the potential for reducing damage (the difference between losses due to disasters without an early warning system and the reduction in losses after an early warning system) is greater than the investment cost of providing the tool, E (Expected Benefit) ≥ C (Cost). The smaller the damage caused by the earthquake, the higher the benefit value. The early warning system can positively impact society and the environment when the benefits have a greater value than the costs.

Besides that, *the expected benefit* of a disaster early warning system is influenced by how much the recipients of the information respond to the information, the accuracy of the information, the number of costs (investment and operational/maintenance costs), the amount of inflation, depreciation, and the frequency of disasters.

Cost value

This study divides the cost into two values: investment and operational costs. According to Jin & Lin (2011), investment costs are the earthquake's early warning system's initial long-term costs. The investment costs used in this study include planning costs, purchasing early warning system equipment, purchasing supporting infrastructure, installing early warning systems, developing control centers, and communication networks.

[2]Press release Number 474.Pers/04/SJI/2022 dated November 21, 2022, M5.6 Earthquake Shakes Cianjur, Geological Agency Immediately Sends Emergency Response. https://www.esdm.go.id/id/media-center/arsip-berita/gempa-m56-goyang-cianjur-badan-geologi-segera-kirim-tanggap-darurat-

Operational costs are costs incurred in carrying out disaster activities. The costs used in this study include maintenance costs, employee training and education costs, operational employee salaries, supervision costs, electricity costs, and community education costs.

Benefit Value

This study only calculates the benefit or value that can be calculated. This study calculates the benefit value based on research by Fahruddin and Schick (2019). The benefit value of the early warning system calculated in this study can be seen in the table below.

Table 1. Benefits of Early Warning System

Type of Impact	**Without Early Warning System**	**With Early Warning System**	**Damage Reduction (%)**
Agriculture and Livestock	Food crops, fruit damaged	At least 10% of damage can be avoided through early harvest.	Lead time - 24 h: 10% - 48h: 30% - Up to 7days : 70%
	Buildings, machinery, and equipment used for agricultural production were damaged.	At least 70% of machinery and equipment can be saved by preventing exposure to hazards.	
	Agricultural inputs like fertilizers, seeds, and chemicals need to be included.	Moving to a safer place or preventing exposure to the hazard can avoid at least 80% of damage.	
	Death of livestock such as cows, goats and poultry	50% of the damage could have been avoided.	
Housing & and household items	Home damage; loss of household property	- Home damage was sometimes avoided (damage due to fallen trees was reduced in 10% of homes damaged by tree maintenance), and depending on the lead time, many or most household possessions were saved. - Property can be saved	Lead time : - 24 hours: 20% - 48 h: 80% - Up to 7 days: 90%

Type of Impact	Without Early Warning System	With Early Warning System	Damage Reduction (%)
Schools, government, administration, banking and finance	Damage to infrastructure, furniture, equipment, and educational materials	15% of damage is avoidable	Lead time : - 24 hours: 5% - 48 h: 10% - Up to 7 days: 15%

This study only calculates the economic benefits, such as agriculture, livestock, housing, school buildings, government administration, banking, and finance. When the early warning system has a maximum load time between the warning sign and the occurrence of an earthquake and can be responded to well by the community, it has the potential to reduce losses and can provide great benefits.

Discussion
Early warning systems can reduce losses due to earthquake disasters if the benefits obtained (E) are greater than the costs incurred (C). The smaller the damage caused, the higher the value of the benefits that can be achieved. Two Cost Categories: The costs associated with early warning systems are divided into two categories. First, investment Costs, includes all initial expenses for setting up the system, including planning, equipment purchases, and infrastructure development. Second, operating costs, includes maintenance costs, training, employee salaries, and community education. Research shows that implementing early warning systems can reduce damage in various sectors, including agriculture, livestock, and infrastructure. With sufficient lead time, damage to crops and livestock can be significantly minimized. Research shows that implementing early warning systems can reduce damage in various sectors, including agriculture, livestock, and infrastructure. For example, with sufficient lead time, damage to crops and livestock can be significantly minimized.

CONCLUSION

Indonesia is a country that is prone to natural disasters, especially earthquakes and tsunamis. Because the losses caused by natural disasters are huge, Indonesia needs an early warning system for disasters. This study aims to analyze the value of costs and benefits/losses that can be avoided if the early warning system for the earthquake in Cianjur, West Java, in 2022 works accurately, and recipients of information can respond to information as quickly as possible.

The results of the analysis show that the expected benefit of a disaster early warning system is influenced by how much the recipients of the information respond to the information, the accuracy of the information, the costs (investment and operational/maintenance costs), inflation, depreciation, and the frequency of disasters.

The government, through the Ministry of Finance, needs to formulate a Disaster Risk Financing and Insurance (PARB) strategy based on considerations of (1) the gap in disaster financing and (2) government priorities. This PARB strategy emphasizes the government's strategy for (i) providing adequate and sustainable funds for disaster risk financing, (ii) financing government priorities in PARB, (iii) improving fiscal management of disasters and optimal and transparent fund distribution channels, and (iv) encouraging the involvement of local governments, the private sector, and the community in a broader financing scheme.

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