Sustainable and Resilient Infrastructure

A Sustainability-based Model for Dealing with the Uncertainties of Post-Disaster Temporary Housing

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Abstract

In the aftermath of natural disasters, temporary housing (TH) needs to be provided for displaced people to mitigate human suffering. In the numerous cases in which a chosen TH strategy is unsuitable for the case-specific local conditions, the TH's negative impacts tend to intensify, especially when decision-makers have to change their initial plan. The unsuitability of the initial plans and the resulting need to change them are usually due to the uncertainty of post-disaster conditions. As most TH provision strategies have weaknesses, the most suitable strategy will thus be the one that best matches the specific circumstances of each scenario. This paper presents a new model to determine the most appropriate strategy to minimize conflicts between local requirements and TH characteristics. The model was calibrated by analyzing the 2003 earthquake in Bam, Iran, and the 2004 earthquake and tsunami in Aceh, Indonesia.

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1. Introduction

An average of 22.5 million people have lost their homes each year since 2008 due to climate- or weather-related disasters. Moreover, this trend is expected to intensify in the future due to the increase in such weather-related events and population vulnerability (Fankhauser and McDermott 2014; Yonetani 2015). Therefore, all areas prone to natural disasters should have a resilience program in place to deal with the accommodation of potentially displaced people (DP) covering not only the items to be provided, but also the impacts of the massive provision of temporary housing (TH) for years to come (Yu and Wen 2016).

TH is intended to provide protection against climate-related factors, disease, and other possible dangers (Babister and Kelman 2002; Collins et al. 2010; Davis 1978). However, it also has considerable negative economic, social, and environmental impacts (El-Anwar et al. 2009a, b; Hadafi and Fallahi 2010; Wei et al. 2012). Additionally, because the issue affects various stakeholders with different, sometimes conflicting, requirements, the chosen strategy is unlikely to completely convince all the beneficiaries.

The aforementioned problems can be exacerbated when decision-makers are forced to change an initially chosen strategy in order to select a more suitable one due to uncertainties. Although the new recovery strategy may lead to higher satisfaction among the DP than the previous one, the process of changing strategies can be time-consuming, energy-consuming, and costly. In this case, Da Silva (2010) found that the multiple changes made to the strategy for Aceh's recovery program led to late delivery, additional expenses, and poor quality. Likewise, poor initial site selection for the temporary housing units (THUs) after the 2003 earthquake in Bam led to their rejection (Ghafory-Ashtiany and Hosseini 2008; Khazai and Hausler 2005), compelling decision-makers to change the strategy after a considerable number of THUs had already been erected. Such situations show that had the decision-makers in both cases being aware of these outcomes and, thus, chosen the most suitable strategies from the start; these could have reduced the negative impacts.

In this regard, although experts suggest defining recovery program scenarios before a natural disaster strikes, few studies have dealt with the uncertainties related to TH programs. Additionally, it is difficult and complicated to compare heterogeneous alternatives due to their disparate features; however, decision-makers must deal with heterogeneous alternatives, referred to here as TH strategies, to determine the most suitable policy. For example, tents, rental accommodations, and

THUs are heterogeneous TH alternatives, whereas steel and timber units, which could both be categorized as THUs, are homogeneous TH alternatives.

Thus, the **objective** of the current paper is to present a method for dealing with TH strategy selection that reduces negative impacts by overcoming uncertainties in the data. In other words, this method aims to assist decision-makers in choosing the most suitable strategy by considering individual local conditions, which, in turn, will lead to higher beneficiary satisfaction. Furthermore, this method should be able to distinguish the most suitable response from among various heterogeneous alternatives.

The remainder of this paper is organized into three sections: (1) a description of the TH concept and its most important characteristics, including life-cycle phases, sustainability aspects, and decision-making issues; (2) an explanation of a new method, called the "steps scenario" method, for identifying the most suitable TH strategy; and (3) case studies of the recovery programs implemented in Bam, Iran (2003), and Aceh, Indonesia (2004), to clarify and calibrate the model.

2. Temporary housing

The TH phase usually spans a period of time ranging from a few weeks after the natural disaster to the completion of the permanent housing, which normally takes a few years. The TH phase provides the necessary conditions for DP to return to their normal activities (Collins et al. 2010). For instance, it provides the same food, work, etc., as before the natural disaster by supplying TH, such as hotels, rental apartments, THUs, mobile homes, etc. According to Johnson (2009), TH can generally be divided into categories. The first is *available TH* that existed prior to the natural disaster (i.e., that does not need to be constructed), such as existing rental accommodations or some collective living quarters, which have been defined by the UN (United

Nations (UN), 2013). The second is *unavailable TH* (i.e., TH that needs to be constructed), such as mobile housing units (shipping containers, trailers, etc.) or THUs.

Furthermore, certain types of accommodations can be used for different housing recovery phases. These accommodations can be divided into four groups: emergency shelter, temporary shelter, TH, and permanent housing (Quarantelli 1995). For example, tents or winterized tents, which can be used for emergency shelter, can also be used in the temporary shelter and TH phases, as in the Aceh case.

3. Most effective vertices for choosing temporary housing

According to Da Silva (2010), the DP's skills and abilities, the availability of local materials, the housing design and construction type, the reconstruction timescale, and funding availability are all essential factors for choosing the most suitable recovery programs. Additionally, different areas with different local living standards and levels of prosperity need to use specific strategies (Ye 2014). For instance, UNDRO (1982) found that rural populations are more able to provide self-built shelter than urban ones. In general, it can thus be concluded that one of the most critical aspects of choosing TH is local characteristics, including local conditions and the characteristics of the affected population itself. Therefore, the strategy for selecting appropriate TH is derived from how well the features of the TH match the local conditions. However, the type and intensity of the natural hazards can also have a considerable impact on this strategy in terms of the amount of damage and limitations caused. For example, in the aftermath of Hurricane Katrina, the authorities were forced to wait to provide TH until after the area could be pumped dry. Thus, the main vertices of TH provision can be grouped into three aspects: (1) local conditions, (2) the characteristics of the natural hazard, and (3) the characteristics of the TH (Hosseini, Pons, Arroyo,

& de la Fuente 2016). The most suitable TH strategy can be determined based on the integration of these three vertices, as shown in Fig. 1.

Fig. 1. Three most effective vertices for choosing temporary housing

4. Decision-making issues in temporary housing

As noted, several factors and indicators are involved in the decision-making process required for post-disaster TH. Consequently, experts in a variety of disciplines should be involved in the process of providing TH for the settlement of DP with different characteristics and abilities (Lin & Wang 2016). Furthermore, final decisions made under pressure in the aftermath of a natural disaster have a high likelihood of failure (Lizarralde & Davidson 2006). According to most researchers and experts in the field, it is better to prepare a pre-plan before a natural disaster strikes based on probabilistic scenarios. Although this approach has numerous advantages, it also involves a considerable amount of indeterminate information and uncertain parameters (Jaeger et al. 2013). Additionally, these indeterminate data are different in each recovery program scenario, requiring a specific local response.

The main indicators of the TH selection decision-making tree presented in Fig. 2 need to be defined in order to choose the most suitable TH. However, it is not always possible to obtain the values of some of these indicators when the TH is selected prior to a disaster, especially in the case of natural hazards (Blaikie et al. 2014). Accordingly, researchers in various fields are struggling to solve uncertainty issues. However, until human knowledge can overcome uncertainty issues (Kuklicke and Demeritt 2016; Špačková & Straub 2017; Zhang et al. 2018), it is vital to find other approaches to address this problem. In other words, decision-makers need to have clear and complete data from each branch of the decision-making tree to obtain ideal results. For instance, as shown in Fig. 2, decision-makers will not have the final information regarding local infrastructure, facilities, and financial power before a natural disaster occurs, even though experts need it to determine the best TH alternative. Similarly, the DP's features considerably impact the choice of a TH strategy, as well as the other components of the decision-making tree, which is shown in Fig. 2.

Fig. 2. Decision-making tree for TH selection

To sum up, most input layers of the TH problem involve high levels of uncertainty. As Fig. 3 shows, the input data include the three main vertices discussed above. Once the data have been entered, the cognitive process section can be divided into two groups: (1) possible alternatives, and (2) decision-making parameters. In addition to the uncertainties of the input data, these two groups of the cognitive process face other problems of undefinition. For instance, tents can be erected as TH at an appropriate site location when the two conditions are considered. First, the affected area must have the required number of tents, a suitable site location, and the necessary infrastructure; second, the use of tents must be consistent with local climate conditions, the expected cost of the TH program, the DP's quality of life and expectations, etc. Thus, the first group, which includes tent availability, appropriate site location, and so on, is the *possible alternatives* group. The second group, which includes factors such as weather conditions, features of the DP, etc., and encompasses all boundaries, limitations, and requirements, would be the *decision-making parameters* group. These two groups could be established for all types of TH, such as rental accommodation (hotels, rental units, etc.), the core housing concept, THUs, and so on. Such categories help decision-makers detect uncertainty issues affecting the TH with a lower margin of error. Meanwhile, the uncertainties of both groups of the cognitive process section are different but related (linked). In this regard, probabilistic scenarios have to be assessed based on the various possible conditions of the elements of the cognitive process and alternative groups.

Fig. 3. Decision-making process for post-disaster TH

To this end, numerous scenarios for various elements of the two groups (*possible alternatives* and *decision-making parameters*), along with combinations of elements from both groups, should be considered to solve the problem accurately. However, many response scenarios are challenging to assess due to the uncertainty of the factors and interconnections (Dovers, and Handmer 1992), especially for areas that are prone to natural disasters but lack precise databases. To address this problem, several scenarios can be assigned to smaller groups of response scenarios. Indeed, each scenario should encompass a wide range of scenarios in order to achieve optimal results. Nevertheless, the small group of response scenarios would not lead to a fool-proof conclusion; it would determine suitable results by considering limited proposals based on uncertain parameters. This tactic could be applied as a compromise solution, rather than taking into account just one response scenario or trying the difficult, slower, and more tedious options of countless scenarios.

Finally, it should be noted that the most suitable alternative (Fig. 3) could vary among recovery programs depending on local characteristics and needs. Therefore, some aspects of the decision-making parameters should be determined based on the desired results. In the current study, the most suitable alternatives were considered to be the selected alternatives with the highest sustainability index (SI). In general, it is essential to determine what would constitute proper results for each case before the decision-making process is undertaken in order to define the ultimate goal so that the decision-making parameters can be designed accordingly. The current paper uses the SI as a normative guideline to assess the suitability of the results. Thus, in this research, the different elements of the decision-making parameters are defined with a view to selecting the alternative that most closely matches the optimum results.

5. Sustainability indices of temporary housing

According to the most relevant studies on TH (Arslan 2007; Davidson et al. 2007; Félix et al. 2013; Hui 2012; Johnson et al. 2006; Johnson 2009; Kennedy et al. 2008Omidvar et al. 2011; Omidvar et al. 2013; Yu and Wen 2016), the essential factors to be considered to properly implement TH are as follows: (1) short delivery time, (2) fit with the DP's culture, (3) acceptable privacy, (4) safety conditions, (5) comfort, (6) reusability, (7) DP's participation, (8) suitable communication, (9) ease of construction and transformation, (10) low cost, and (11) minimum impact on the environment. Additionally, sustainability codes can be applied depending on the type of TH to be used in the short term in a specific situation. The sustainability indicators can thus be organized into three main indices – (1) economic, (2) social, and (3) environmental – (see Table 1) in accordance with the aforementioned factors and a sustainability concept based on (Halliday 2008; Häkkinen et al. 2012).

Table 1. Definition of temporary housing sustainability indicators

The main sustainability indicators are defined in Table 1. Each indicator can, in turn, be broken down into several sub-indicators, which are mentioned in the Definitions section. Additionally, sub-indicators can vary based on individual cases and TH life-cycle phases, as shown in Fig.1. Some indicators, such as the *match with local technologies* indicator, can be assigned to the main sustainability vertex, since this indicator has considerable impacts these whereas quite differently. Meanwhile, other indicators, such as the *maintenance cost* indicator, which must be assessed in the operation phase, only belong to one phase. Furthermore, the priority of each indicator can be completely different from one scenario to the next for each case, as well as between different cases. The priority assigned to each factor thus needs to be evaluated by experts and local decision-makers. The current paper does not include a separate indicator for policy-makers, as they are among the stakeholders who decide the distribution weights along with the technicians, authorities, and experts.

6. Proposed model

Generally speaking, there are multiple ways to deal with uncertainties, such as the Monte Carlo methods. However, different approaches are required to deal with the uncertainties surrounding TH programs due to their specific features, such as a large number of stakeholders with expertise on various aspects of the issue, the urgency and need for speed, the ambiguity, and so on.

The current paper presents a model based on a steps scenario, consisting of a comprehensive strategy for choosing the most suitable TH approach (plan), as shown in Fig. 4. This steps-scenario method was designed to select the most suitable alternatives by presenting a solution to deal with the uncertainties of TH elements. This method simultaneously considers two points: (1) the availability of the alternatives, and (2) the suitability of the available alternatives with regard to the local requirements and case-specific ideal alternative. This method could be used to identify a suitable response among heterogeneous alternatives. Fig. 4 shows the steps-scenario method for dealing with the general TH strategy. This method is used for the initial and intermediate phases of the general methodology, e.g., rental accommodation, trailers, and THUs. Although it could also be used to consider homogenous alternatives, such alternatives would be more efficiently assessed using other methods, such as MCDM. That would be the case, for instance, with the assessment of multiple THU alternatives, such as various prefabricated technologies and masonry. On the other hand, to determine the most suitable alternative among various choices for a single TH strategy (homogenous alternatives), the final phase should be used. This phase has been extensively described in Hosseini et al. 2016a, b.

Fig. 4. The general methodology for selecting sustainable TH, including the three phases

6.1. Steps scenarios

Steps scenarios offer decision-makers minimum- and maximum-quality alternatives based on the results for local conditions. The more scenarios that are considered between the minimum- and maximum-quality alternatives, the more accurate the outcomes of the steps taken following a natural disaster will be. This new model considers various elements of the *decision-making parameters* and *available alternatives* groups across and/or within each group, as shown in Fig. 3. It then offers several series of responses rather than a single absolute response. These series range from ideal to less suitable solutions. Therefore, decision-makers can choose the most appropriate solution based on an actual situation, aware of the solutions' positive and negative impacts.

In the first step, decision-makers choose the most suitable alternative features. They then define and assess elements of the cognitive process. For instance, various scenarios can be designed based on possible TH and DP numbers. The first scenario considers the highest-ranked TH type with regard to suitability and availability in terms of the number of DP who could be covered by it, as shown in Fig. 5. In the following scenarios, other possible accommodations are considered in case DP requests for TH exceed the number of alternatives provided for in the previous step, also as shown in Fig. 5. The solutions offered in these additional steps could have negative results. However, decision-makers would at least be aware of these possible negative impacts. Additionally, as the most suitable alternatives have already been used, there is no longer any choice but to use other less suitable alternatives. This approach thus makes it possible to maximize the use of local potential and prevents resources from being wasted. As a result, the steps-scenario approach reduces the negative impact trend of the alternatives.

Fig. 5. Relationship of sustainability indices to DP in steps scenarios

In the current study, the most suitable results are determined based on the SI, which, in turn, can be calculated according to various aspects, such as costs, transportation needs, flexibility, cultural acceptance, suitability to local climate conditions, available skilled labor, etc. (UNDRO 1982). Indeed, if SIs are considered to range from zero (minimum value) to one (maximum value), the alternative with the SI closest to one should be chosen in the first step. If the selected TH does not cover the total number of DP, the alternative with the next highest SI should be chosen and so on until the entire target population is covered. This methodology is designed to assess TH indicators with high uncertainty. As noted in the section on decision-making problems in the selection of TH, some factors remain unaddressed even when decision-makers have prepared precise pre-plans. Moreover, different scenario designs could encompass all conditions involving uncertainties in order to respond to natural disasters. In such a situation, decision-makers can consider different scenarios based on the available alternatives in a pre-disaster case. Then, should any hitherto undefined information be determined in the aftermath of the natural disaster, when decision-makers evaluate the numbers for both the DP and the habitable accommodations, they can calibrate and apply a scenario that has been customized to the actual conditions. In this regard, the steps-scenario method could be a suitable solution to some of the drawbacks of the community-based approach. Although the community-based approach is widely considered to offer numerous benefits, according to (Davidson et al. 2007, Lin et al. 2016), for example, it sometimes involves uncertainties regarding community requirements and reactions. The steps-scenario method thus offers a way for decision-makers to address unconsidered and unexpected situations by presenting a range of possible responses.

Although this method has been optimized for application prior to natural disasters, it can also be used in other situations. For example, in a problem area in which there is insufficient information to determine DP numbers based on the three vertices prior to a disaster, steps scenarios can be used with regard to just local potential. To this end, the alternatives with the fewest negative impacts are considered for DP numbers based on their respective capacities. The alternatives with the second lowest SI are applied in a second step should the number of DP increase beyond the capacity of the alternatives provided in the first scenario.

In general, it should be highlighted that the steps-scenario approach described in this paper has been designed to cope with uncertainty regarding the number of DP, the available TH alternatives, and local conditions, as well as to obtain a high SI. Although, the present research considered these issues based on specific cases, the steps-scenario concept could be used for any uncertain information related to TH management. In this regard, this new model calculates the SIs of the alternatives based on a dual-comparison approach and local conditions. Decision-makers then examine the alternatives in relation to the steps-scenario concept, including the DP numbers and the suitability of the alternatives based on local conditions.

7. Case studies

For the purposes of the current study, the new steps-scenario approach was applied to two recent cases of natural disasters that happened within exactly one year of each other. In each case, decision-makers were forced to choose other alternatives during the planning/construction and operation phases. These decision-makers faced uncertain situations and unexpected results. As a result, they chose multiple TH approaches in both cases.

7.1. Iran, 2003

The earthquake that rocked the city of Bam on December 26, 2003, destroyed more than 90% of the buildings in the urban area (Fayazi and Lizarralde 2013). Table 2 shows some factors of the three main vertices (local, natural hazard, and TH characteristics) in the Bam case. The Iranian government selected the Foundation of the Islamic Republic of Iran (HFIR) and the Ministry of

Defense to provide the TH. These two organizations constructed the THUs directly or hired contractors to do it. The authorities decided to use three phases: (1) tent shelters, (2) intermediate shelters, and (3) permanent housing (Khazai and Hausler 2005). To this end, tents and unavailable TH, consisting of prefabricated and in-situ units set up at campsites (grouped) or in the yards of the DP's original homes (dispersed), were used. The Iranian Red Crescent Society provided more than 50,000 tents as temporary shelter within the first day (Ghafory-Ashtiany and Hosseini 2008). Various technologies were used for the TH provision, including pre-fabricated structures and masonry technology both at campsites and on private property. However, decision-makers were ultimately forced to change the campsite strategy to the DP's private yards because the DP did not wish to use the campsite THUs. Therefore, of the 35,905 THUs erected in all, 9,005 were erected at campsites and 26,900 on private property belonging to the DP (Ghafory-Ashtiany and Hosseini 2008).

Table 2. Local characteristics of the two case studies

7.1.1. Bam scenario problem

The Bam authorities decided to set up most of the campsites on the outskirts of the city because of the debris. Additionally, a rental-accommodation strategy was inviable due to the huge number of damaged buildings. Therefore, the decision-makers decided to provide campsites, which required site preparation, utilities, and so on, as well as private sites. According to Khatam (2006), 10%-20% of the THUs at campsites were never occupied. Some campsite units were used to house engineers and aid workers, who came to Bam from other cities to compensate for shortfalls in local human resources. Once it became clear that the DP did not wish to settle at the campsites, the campsite strategy was changed to a private site one in a middle-of-the-road private site strategy. Additionally, some vacant sites began to run into social problems, especially once the THUs had been erected on private property, forcing the authorities to dismantle and remove the problematic campsites. The new decision was ultimately more suitable for the people displaced by the Bam earthquake; however, the change itself led to a waste of time and funding.

Khazai and Hausler (2005) found that it was the DP's concern for their previous properties, as well as the distance to the sites, that led them to reject the campsite THUs. Additionally, the actions taken by the DP, who added components to their THUs to enable greater privacy, suggest that the rejection could also be related to the DP's culture.

In addition to the aforementioned problems, the ill-suited decision-making results led to the waste of considerable capital. Moreover, it increased the waiting time for the TH's delivery to the DP. Although most decisions were made after the Bam earthquake, the failure to take the DP's opinions into account was responsible for the aforementioned problems. In this case, decision-makers were able to determine the number of DP with greater precision; it was the DP's social requirements that should have been given more consideration to avoid unsuitable results. To this end, the current study applies the steps scenario to the uncertainty regarding social requirements in the Bam recovery program. This scenario is based on the analogy of the *decision-making parameters* group with site location from the *available alternatives* group.

7.2. Indonesia, 2004

The earthquake and tsunami that struck Indonesia on December 26, 2004, left approximately 220,000 dead (Steinberg 2007). Some factors of the main vertices are presented in Table 2. The approaches applied in the wake of the Aceh earthquake were the self-help system and third parties. Most of the organizations involved in the Aceh recovery program first proposed using self- or community-build programs (Da Silva 2010). At first, the authorities decided to transition from temporary shelter to permanent housing; thus, tents and barracks were prepared for the DP as the shelter in the TH phase. However, this goal could not be fully achieved. According to Da Silva

(2010), less than half of the considered population had been accommodated in barracks within a year. The decision-makers were thus forced to change their initial strategy and provide different types of transitional shelter to settle the DP until the permanent housing could be completed. Additionally, as shown in Table 2, the tropical climate conditions of Aceh were one of the main reasons for this change in the initial strategy.

7.2.1. Aceh scenario

Several international and Indonesian organizations were involved in the Aceh recovery program in the aftermath of the 2004 earthquake and tsunami. The authorities decided to skip the TH phase to avoid wasting the resources for these accommodations. The tents, which were used as living quarters for the DP, could not withstand the tropical sun and rain (Steinberg 2007). The decision-makers thus changed strategies and provided THUs for the DP. Some of the THUs were then used as the initial part of the core housing.

Even if the tents had been able to withstand the tropical conditions, from the point of view of the DP's satisfaction, they also had certain weaknesses compared to the THUs, such as lesser reusability or a lower ability to ensure health and well-being, among others (see Table 3). However, the tents cost less than the THUs. Thus, the steps-scenario method should take into account both social and economic requirements, which were both included as categories in the *decision-making parameters* group.

8. Analysis

As an example of the presented steps-scenario method, both cases (i.e., the recovery programs following the 2003 earthquake in Bam and the 2004 earthquake and tsunami in Aceh) will be considered. In each case, there were two possible alternatives. In the Bam case, it is necessary to assess two types of site locations – campsites and the yards of the DP's housing – which are elements of the cognitive process section. The two site location types are assigned to the *possible alternatives* group, which needs to be ranked based on the DP's features according to the *decision-making parameters* group. In the Aceh case, it is necessary to consider two TH types – tents and THUs – from the *possible alternatives* group by analogy with economic and social requirements from the *decision-making parameters* group. In both cases, the ideal response will be the alternative with the highest SI for each case based on the specific local conditions.

Each case study has only two possible alternatives to be evaluated with the steps-scenario method in terms of the SI. Thus, the alternatives are compared with each other according to the dual comparison concept in terms of accepted, equal, and rejected points. Furthermore, in both cases, the alternatives are compared based on the indicators shown in Table 3. However, in order to obtain the SI for each alternative, especially in cases where there are more than two, a point assignment system or quantitative method could be applied for each indicator to ensure more accurate results. In other words, various methods and tools can be used to identify the ideal response, which will depend on the local requirements. The parameters obtained for each indicator can then be ordered from 0 to 1 (as the minimum and maximum satisfaction scores) directly or based on the utility theory. Finally, the SI for each case is evaluated as shown in Equation (1). The current study uses a simple model to obtain the SI since, as noted, the main objective is to present the steps-scenario method. To this end, two case studies are considered as examples to clarify the issue.

$$SI = \sum \beta_i \, . \, \lambda_i \, . \, V_i \, (x_i) \quad (1)$$

SI : The sustainability index

$V_i \, (x_i)$: The value function of each indicator.

λ_i : The weight of the indicator.

β_i : The weight of the main index encompassing this indicator.

The weights of the indicators were determined by university professors at seminars held for this purpose based on experience and references using the analytical hierarchy process (AHP) (Saaty 1990), as shown in Table 3. Additionally, a sensitivity analysis was performed considering 22 different scenarios, consisting in modifying the weights of the requirements – within a range of 15% to 70%. These 22 scenarios were conceived based on all the weights assigned by the university professors to the requirements in accordance with various conditions that even included the outliers. Most of the cases were assigned to the middle range, which can obviously be certain weights of the main indices. Other approaches, such as Shannon's entropy, were also applied to determine the weights of these research indicators. For more information, see (Hosseini et al. 2016b, 2018).

Table 3. Assessment of case study alternatives based on sustainability indicators

9. Results and discussion

As shown in Table 4, the most sustainable alternatives in each case depend on the weights assigned to their indicators, which were obtained by means of three approaches. Specifically, these three sets of indicator weights were determined: according to the results of the seminars as shown in Table 3; by weighing all indicators equally; and by Shannon's entropy. The results show that assigning equal weights to all indicators is not a reliable method in either case. This is consistent with the fact that most researchers stress the importance of the indicators involved in a TH issue. Therefore, the current study will focus on the results obtained from the other two weighting systems.

In the Bam case, the SI results clearly demonstrate that TH erected on the DP's private property is more sustainable and better accepted than TH erected at campsites. The private property approach is ranked in the first stage by considering several scenarios based on various weighting systems and distributions. The private-property site is the highest ranked alternative because it offers considerably more benefits and is satisfactory from the points of view of all stakeholders. In this regard, unless the yard alternative was unable to cover the entire number of DP, it was unreasonable to apply the campsite strategy. In short, there were two scenarios: the first, and most suitable, was the yards of the DP's own homes; the second was campsites. If there were no more private land to provide TH in the yards of the DP's previous homes – in other words, if the population density had increased – the decision-makers could apply the campsite solution as the second most sustainable alternative. The results obtained from applying the steps-scenario method to this case demonstrate that the change in site location by the decision-makers was correct and necessary. Notwithstanding the above, this result was obtained based on the SIs, the two alternatives, and the DP's features. However, other factors, such as reconstruction activities and speed, debris relocation, population density, the number of floors of the pre-disaster housing, and so on, also had considerable impacts on the final results.

Table 4. Most sustainable alternative for each case based on different indicator weights

The main challenge and reason for the design of the steps scenario in this research was the Aceh case. In that case, there was a range of responses, each of which might be chosen depending on the specific conditions. In the Aceh case, the two weighting systems (based on the seminars and entropy) yielded different results, which need to be analyzed.

As shown in Fig. 6, changing the weights of the economic and social indices can change the SI trends of the Aceh alternatives. Additionally, the SI shows a non-monotonic sensitivity to the environmental index, as can be seen in the trends. A 55% increase in the weight of the environmental index (from 15% to 70%) leads to disorganized (non-monotonic) changes in the SI, ranging from 0.33 to 0.64. If the economic or social weight is increased, then tents or THUs, respectively, become more sustainable alternatives. In this regard, a decrease of 55% in the weight of the social index (from 70% to 15%) leads to an almost monotonic increase in the SI of the tent alternative, from 0.25 to 0.63, and to a decrease in the SI of the THUs, from 0.72 to 0.36. Therefore, the steps-scenario method gives different alternatives as the most suitable choice depending on the specific requirements and conditions.

Fig. 6. Sustainability indices of the Aceh recovery program alternatives considering: (a) decreasing economic weights based on the seminars; (b) decreasing social weights based on the seminars; (c) decreasing economic weights based on entropy; and (d) decreasing social weights based on entropy

To this end, if the DP's quality of life (i.e., social factors) is the top priority for decision-makers, THUs would be the most sustainable TH for the Aceh recovery program. The decision-makers could begin by providing THUs to the DP, and, only if there were not enough THUs to meet the needs of all the DP, provide tents, the alternative with the second-highest SI, to those people to whom it had not been possible to assign a THU. In contrast, if the authorities wish to prioritize economic aspects, tents would be chosen as the first alternative. In the next step, if not enough tents could be prepared to accommodate all the DP, the THU strategy could be used, as the second-most sustainable alternative.

In general, recovery program strategies are related to several factors, which, as explained, can have opposite impacts in different cases. As the results show, the alternatives with the lowest and highest SIs in each case depended on which requirements were prioritized. Therefore, to solve the post-disaster housing issue, the strengths and weaknesses of the possible strategies must be determined based on the three main vertices (see Fig. 1). Then, the most suitable alternative can be specified based on the individual requirements of each case. Indeed, to make a proper decision on this issue and maximize stakeholder satisfaction, it is necessary to detect problems, define possible responses, determine all the characteristics of these responses based on different conditions, and select an appropriate alternative by considering the fit between the alternative's characteristics, the problems, and the requirements, as the model presented here proposes.

10. Conclusions

This research paper proposes a new model designed to assess the suitability of post-disaster TH alternatives. This model is intended to help decision-makers overcome uncertainties when deciding the best TH options. In this regard, the Bam and Aceh post-disaster situations, in which the recovery strategies had to be changed in terms of site location and TH strategy, respectively, were considered as examples. This steps-scenario method offers an opportunity for decision-makers to choose alternatives beforehand, by considering a range of responses to be applied in various situations. Indeed, this model could play an important role in helping decision-makers avoid selecting TH alternatives for which there are other alternatives with fewer negative impacts. The following conclusions can be drawn from this research:

- One of the main keys of the decision-making process for TH is to address the uncertainty involved in input data after natural disasters. Because of this uncertainty, it is very difficult and inaccurate to present a single response. A wide range of responses could enable decision-makers to overcome the uncertainty of such situations. However, in order to achieve the final goal, various scenarios must be assessed based on different parameters.
- The most suitable or ideal response for each case could vary from one situation to another. Thus, the ideal response needs to be determined during the decision-making process. Consequently, the most suitable response for each case should determine both the form of the decision-making parameters and how they are ranked.

- In this study, the suitability of the TH strategy was determined based on the three vertices and the priorities given to the indicators. Therefore, all strategies need to be considered, even those that seem to have substantial negative impacts, as strategies with obvious weaknesses may nevertheless be more suitable than other alternatives when the entire life cycle of the TH, the requirements of all beneficiaries, and individual local conditions are taken into account.
- The sustainability indices of the alternatives for the Bam and Aceh cases show that decision-makers did well to change their initial strategies. However, changing the initial strategies had negative implications, such as wasted time and financial resources. In this sense, the decision-makers in both cases would have benefited from a model such as the one presented in this study, which would have allowed them to identify the most suitable alternative in the first stage of the planning phase.

The main limitation of this study is that it applied only one simple decision-making method. Future research should examine the use of the steps-scenario strategy with a variety of decision-making methods. In this regard, future studies could compare different decision-making models in order to determine which ones are most accurate and best match the steps-scenario strategy.

NOMENCLATURE

SI	:	Sustainability index
V	:	Value function
Ec.	:	Economic
S.	:	Social
En.	:	Environmental
TECH	:	Technology
SD	:	Severely damaged
CB	:	Collapsed building
MIN	:	Minimum
MAX	:	Maximum
TEMP	:	Temperature
A	:	Accepted
E	:	Equal
R	:	Refused
P	:	Private yard of DP´s previous housing
C	:	Camp site
T	:	Tent
U	:	Unit/THU

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Table

Table 1. Definition of temporary housing sustainability indicators

Main Index	Main Indicator	Definition	Reference
Economic	Provision cost	Considers all expenditure which is required for providing TH (e.g. renting, land price, construction cost, material cost, and utilities cost)	Halliday 2008; Häkkinen et al. 2012; Hosseini et al. 2016a,b
	Maintenance cost	Takes into account activity and material cost during and after DP usage	Halliday 2008; Häkkinen et al. 2012; Hosseini et al. 2016a,b
Social	Health	Presents mental and physical factors of involved people in TH program and includes security, risk resistance, water and sanitation, infrastructures, communications, etc.	Amini Hosseini 2013; Da Silva 2010; Halliday 2008; Häkkinen et al. 2012; Rahmayati 2016; Sutley & Hamideh 2017
	Well-being	Embraces all those elements that provide comfort for DP: TH delivery time, access, facilities, privacy, climate comfort conditions, participation, etc. Additionally, this indicator embraces well-being of third-parties, such as neighbour acceptance	Amini Hosseini et al. 2013; Da Silva 2010; Doorn et al. 2018; Fayazi 2011; Ganapati 2013; Hayles 2010; Kennedy et al. 2008; McCarthy 2014; Pearce 2003; Reiner & Rouse 2017; Taheri Tafti & Tomlinson 2013, 2016
	Culture	Considers the fitting range of TH to DP´s culture	Hayles 2010; Tucker et al. 2014; UNDRO 1982
Environmental	Resource consumption	Takes into account consumed material, water, and energy for all phases	Gangolells et al. 2009; Häkkinen et al. 2012; Halliday 2008; Hayles 2010; Hosseini et al. 2016a,b
	Pollution	Includes all improper gas emissions and liquids leach	Häkkinen et al. 2012; Halliday 2008
	Solid waste	Takes into account waste materials	Gangolells et al. 2009; Häkkinen et al. 2012
	Reusability	Considers TH possibilities factors for second life	Arslan 2007; Häkkinen et al. 2012; Hayles 2010

Table 2. Local characteristics of the two case studies

Case study	Local potential							Affected population			References
	Building			Climate condition			Population	Death	DP		
	TECH (Pre-disaster)	SD/CB (Nº)	SD/CB (%)	MIN TEMP (C)	MAX TEMP (C)	Rainfall (mm)[a]			(Nº)	(%)	
Iran 2003	Brick and Steel, Adobe, others	52,756[b]	80%	-2	44	62.5	142,376[b]	31,383	65,000[c]	50%	Ghafory-Ashtiany and Hosseini 2008; Klugman 2011
Indonesia 2004	Timber, Brick	116,880	57%	22	34	1,600[d]	4,000,000	167,000	500,000	12.5%	Da Silva 2010; IFRC 2007; Klugman 2011; Sari 2011; Steinberg 2007

(TECH: Technology; SD: Severely damaged; CB: Collapsed building; MIN: Minimum; MAX: Maximum; TEMP: Temperature)

[a] Average annual

[b] Urban and rural population of Bam in 1996

[c] Khazai and Hausler (2005) stated the all number of people, including population of Bam and surrounding villages, and migrants, who needed to shelters were 155,000.

[d] On coast

Table 3. Assessment of case study alternatives based on sustainability indicators

Case	Alternative	**Economic**		**Social**				**Environmental**		
	Indicator	Expense	Maintenance	Health	Well-being	Culture	DP Distribution	Consumption	Pollution	Reusability
	Weight	75%	25%	45%	15%	25%	15%	35%	30%	35%
Bam	Camp	R	R	R	R	R	A	A	E	E
	Private	A	A	A	A	A	R	R	E	E
Aceh	Tent	A	R	R	R	R	E	A	A	R
	THU	R	A	A	A	A	E	R	R	A

(A: Accepted; E: Equal; R: Refused)

Table 4. Most sustainable alternative for each case based on different indicator weights

Case	**Weight** / **Main Index** / **Technique**	**70Ec/15S/15En**	**50Ec/30S/20En**	**50Ec/25S/25En**	**48Ec/30S/22En**	**48Ec/22S/30En**	**47Ec/35S/18En**	**47Ec/18S/35En**	**45Ec/25S/30En**	**42Ec/36S/22En**	**42Ec/22S/36En**	**38Ec/33S/29En**	**38Ec/42S/20En**	**36Ec/42S/22En**	**35Ec/47S/18En**	**30Ec/48S/22En**	**30Ec/45S/25En**	**25Ec/50S/25En**	**20Ec/50S/30En**	**20Ec/30S/50En**	**15Ec/55S/30En**	**15Ec/70S/15En**	**15Ec/15S/70En**
Bam	**Seminars**	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
	Equal	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	C
	Shannon's Entropy	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	C
Aceh	**Seminar**	T	T	T	T	T	U	T	T	U	T	U	U	U	U	U	U	U	U	U	U	U	T
	Equal	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	U	T
	Shannon's Entropy	T	T	T	T	T	T	T	T	T	T	T	U	U	U	U	U	U	U	T	U	U	T

(P: private yard of DP´s previous housing; C: camp site; T: tent; U: unit/THU)

Figure

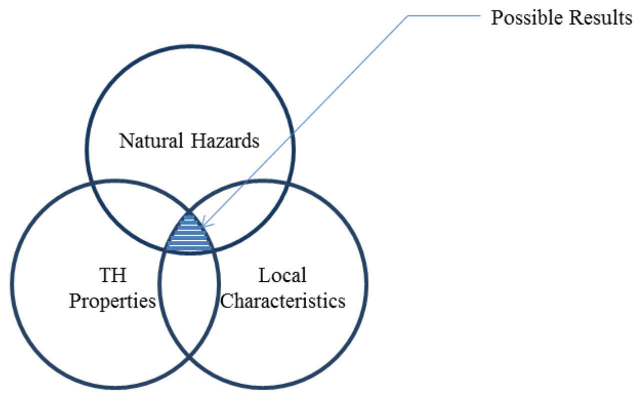

Fig. 1. Three most effective vertices for choosing temporary housing

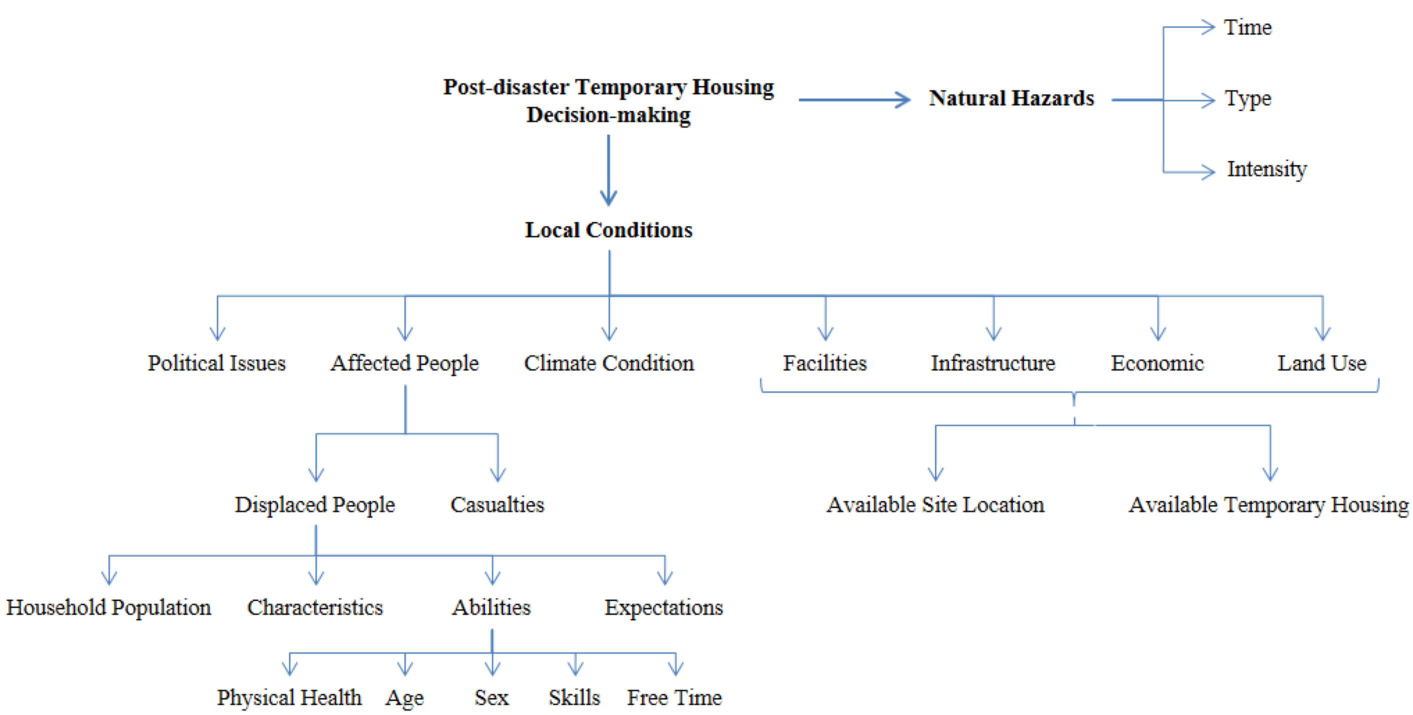

Fig. 2. Decision-making tree for TH selection

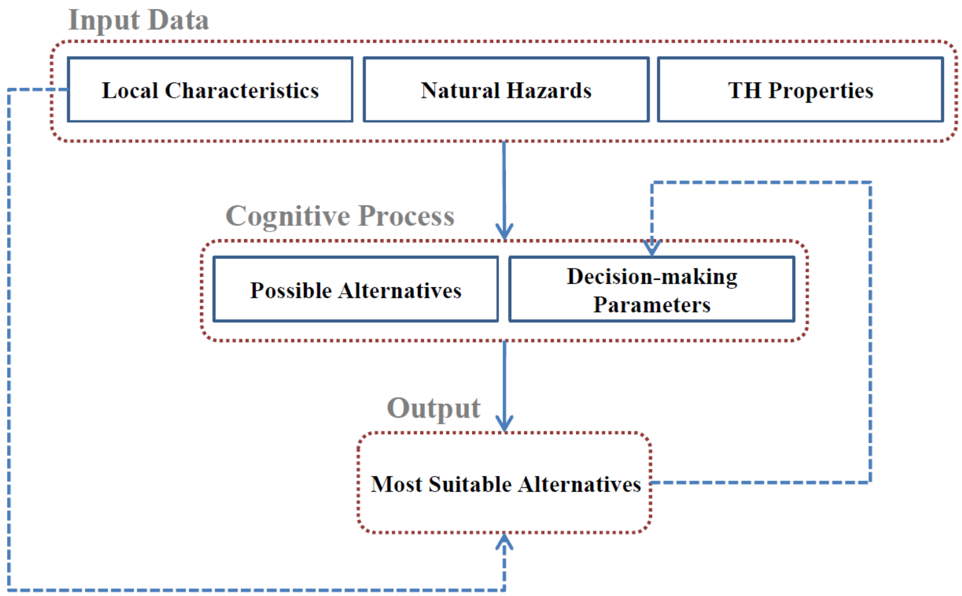

Fig. 3. Decision-making process for post-disaster TH

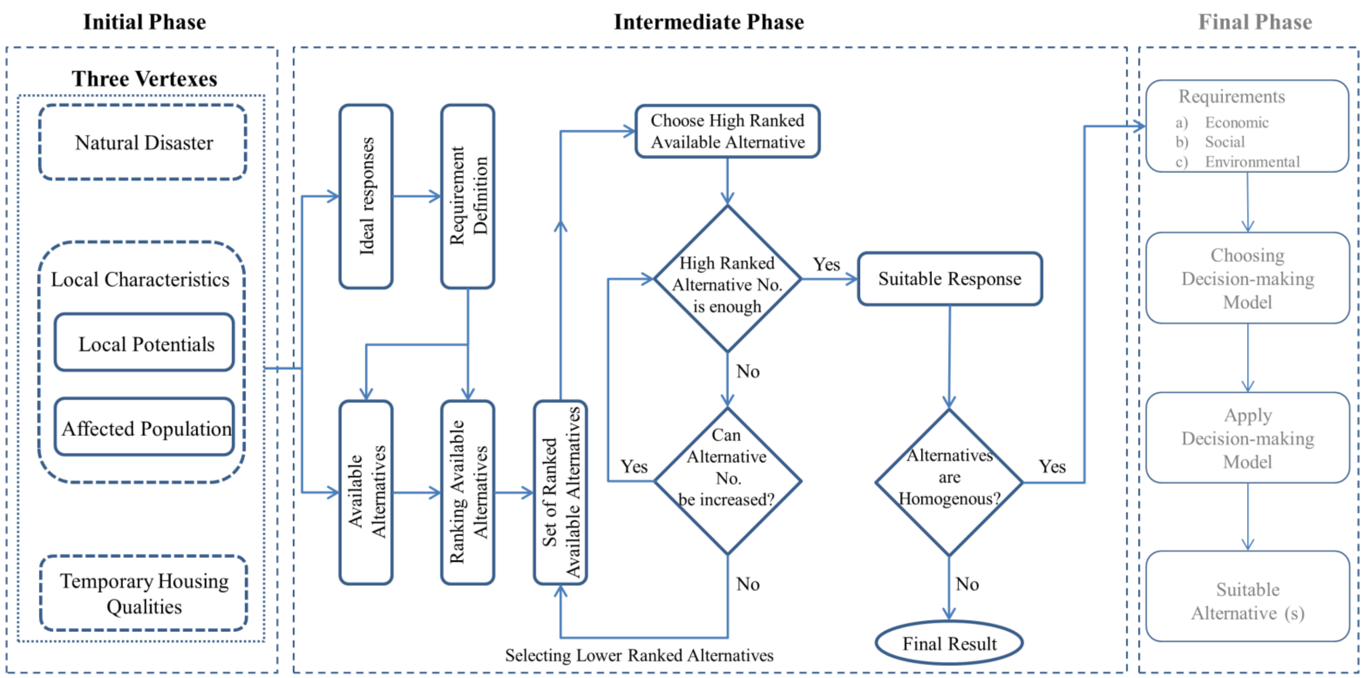

Fig. 4. The general methodology for selecting sustainable TH, including the three phases

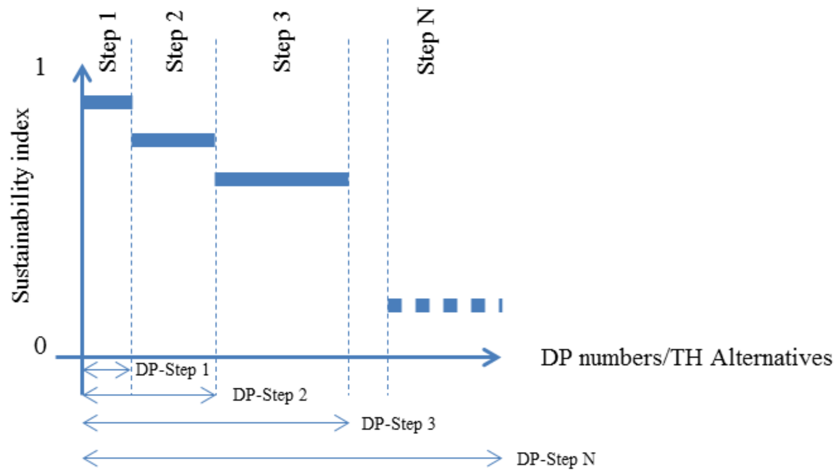

Fig. 5. Relationship of sustainability indices to DP in steps scenarios

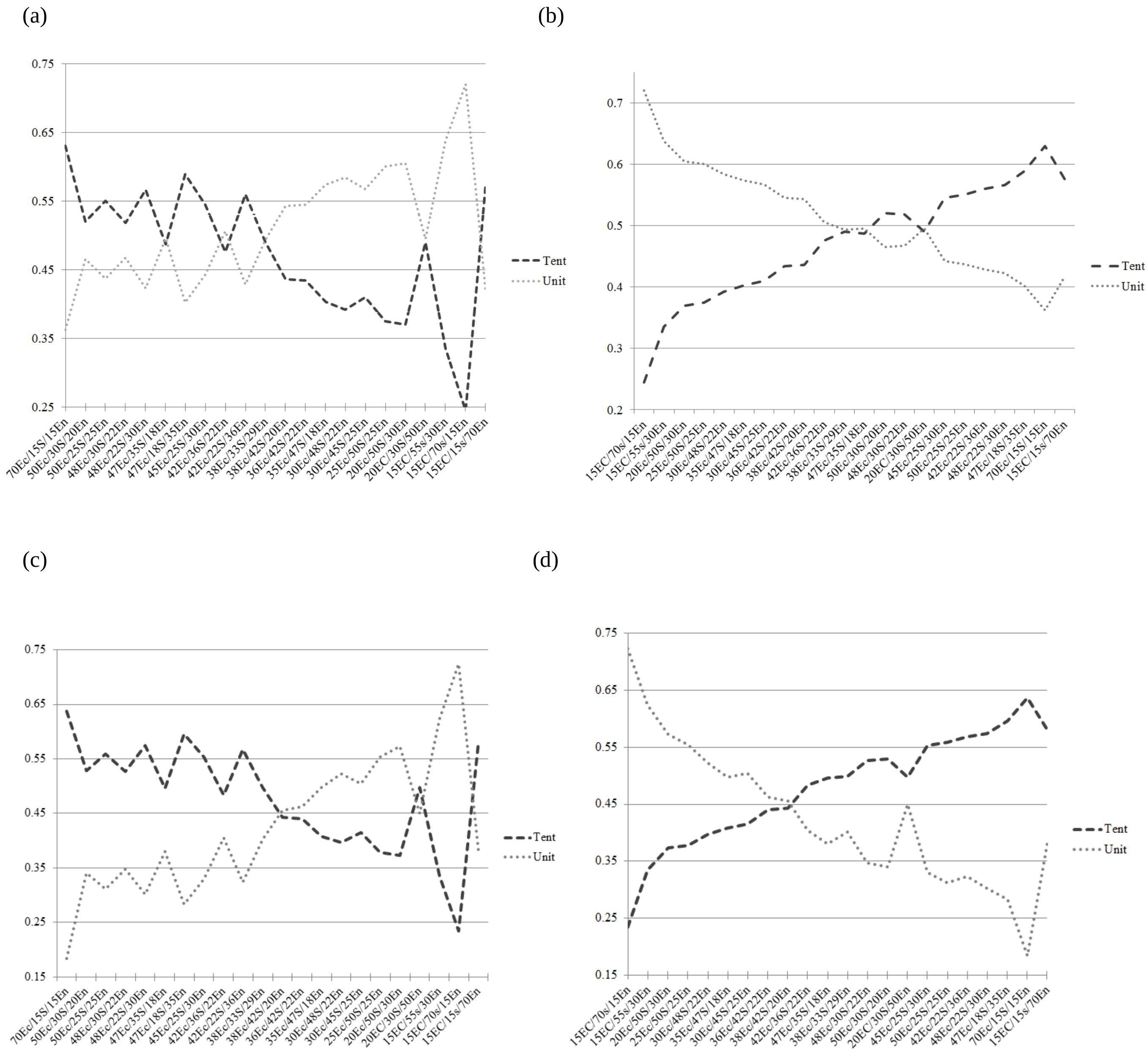

Fig. 6. Sustainability indices of the Aceh recovery program alternatives considering: (a) decreasing economic weights based on the seminars; (b) decreasing social weights based on the seminars; (c) decreasing economic weights based on entropy; and (d) decreasing social weights based on entropy