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*Article*

# Determining the Location of the National Repository of Italian Radioactive Waste: A Multi-Risk Analysis Approach

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**Abstract:** Following the 1987 referendums, the Italian government stopped its nuclear energy production. Radioactive waste produced by existing nuclear facilities and the very-low- and low-level radioactive waste due to other activities (e.g., healthcare) require the construction of a National Repository. To this end, the National Map of Suitable Areas (CNAI), through which the optimal site to host the National Repository would be identified, was published on 23 December 2023. Over the years, the possible location of the National Repository has been repeatedly contested by the citizens of the territories concerned. However, the need to identify a site and build the National Repository is unavoidable. This study proposes an approach based on multi-criteria analysis. The approach represents an alternative model useful for enriching the public debate with additional information and criteria and is also consistent with the local needs of the communities involved. The proposed approach compares the sites proposed in the CNAI by analyzing their main short- and long-term risks, namely their seismic, transport-related and socio-economic risks. The obtained results show a possible different priority order of the CNAI sites. They highlight the possibility of identifying the optimal site mainly via using site safety criteria assessed throughout the entire service life of the infrastructures to be built and also consider the possible short-term economic advantages deriving from the construction of the National Repository.

**Keywords:** risk analysis; radioactive waste; national repository; technology park; national deep geological repository; seismic engineering; decision-making

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## 1. Introduction

Italian nuclear energy production began in 1963 with the construction and activation of the first power plant in Latina [1], Latium region. At the time, it was the most powerful nuclear power plant in Europe. The following year, the Garigliano [2] and Trino [3] power plants were completed in the Campania and Piedmont regions, respectively. Subsequently, from 1970 to 1978, the Caorso nuclear power plant [4] was also built in the Emilia-Romagna region to increase nuclear energy production. Meanwhile, during the 1960s and 1970s, four nuclear fuel production and research facilities were built and put into operation to ensure the fuel cycle for the four Italian nuclear power plants. They are the OPEC and IPU plants [5] in Casaccia (Latium region), the ITREC plant [6] in Rotondella (Basilicata region), the EUREX plant [7] in Saluggia (Piedmont region) and the FN plant [8] in Bosco Marengo (Piedmont region).

In addition, twelve other facilities were involved in the main production and storage of nuclear waste. They are the Ispra-1 reactor [9] located in the Joint Research Center

(JRC) in Ispra (in the Lombardy region) and the following facilities [10]: (i) seven nuclear research centers (ENEA Casaccia, CCR Ispra, Avogadro Repository, LivaNova, CESNEF-Enrico Fermi Center for Nuclear Studies, University of Pavia, University of Palermo); (ii) three operational Integrated Service centers (Nucleco, Campoverde, Protex); iii) and an Integrated Service center which is no longer active (Cemerad). There are also numerous nuclear medicine centers on the Italian territory, including hospitals. These healthcare centers retain most of their radioactive waste.

The Three Mile Island accident [11] in the United States, the 1980 Irpinia earthquake [12] in Southern Italy and the 1986 Chernobyl nuclear disaster [13] in Ukraine profoundly influenced the public perception of the risks associated with nuclear energy production [14]. Growing concerns about the safety of nuclear power plants led to the 1987 Italian referendums [15], in which Italian voters expressed their will to move away from nuclear energy production. As a result, existing nuclear power plants were gradually decommissioned and related nuclear activities stopped.

In 1999, Sogin (an Italian state-owned company) was formed to take over the four nuclear power plants and be responsible for their safe maintenance and decommissioning [16]. Furthermore, it also had to take responsibility for managing all Italian nuclear waste, and in 2003, the Italian government entrusted Sogin with the decommissioning of the four nuclear fuel production and research facilities.

In 2009, Italian legislation attempted to reconsider nuclear energy as an alternative energy source by planning a new nuclear program to achieve a 25% nuclear-powered electricity supply by 2030 [17]. However, the Fukushima nuclear accident [18] in Japan caused by the 2011 Tōhoku earthquake and tsunami [19] further increased the skepticism of Italians, and the 2011 referendum [20] once again confirmed the popular will to abandon nuclear energy production, rejecting this prospect of electricity supply.

With the Decree of the President of the Council of Ministers (DPCM) dated 14 February 2003 [21], the Italian government declared a state of emergency in order to implement extraordinary and urgent intervention measures aimed at the safe disposal of radioactive waste located in the Basilicata, Campania, Emilia-Romagna, Latium and Piedmont regions. Consequently, Sogin initially identified the municipality of Scanzano Jonico (near the ITREC plant in Rotondella, Basilicata) as the site for the construction of a National Repository (hereafter, the Repository) without the participation of all stakeholders in the decision-making process [22]. Accordingly, in November 2003, a peaceful but very significant and well-attended popular protest took place. In response, the government decree and the choice to locate the Repository in Scanzano Jonico were annulled.

Since 2004, Sogin has taken on the task of managing radioactive waste generated by industrial, healthcare and research activities, and in 2018, it was also entrusted with the decommissioning of the Ispra-1 reactor [16]. With the aim of safely managing and storing all Italian radioactive waste, Sogin is working to locate, design and build the Repository in a transparent, shared and participatory way [23,24]. Today, the twelve facilities involved in the main production and storage of nuclear waste, together with the four nuclear power plants and the four nuclear fuel production and research facilities, are the twenty sources that govern the geographical distribution of Italian radioactive waste [10]. As specified in the Legislative Decree 31/2010 [23], the Repository will be a near-surface disposal facility that will permanently host low- and intermediate-level radioactive waste derived from anthropic activities. Furthermore, high-level radioactive waste and irradiated fuel from the previous management of nuclear plants will be stored in a separate unit of the Repository in the interim, pending the construction of a National Deep Geological Repository (hereafter, DNPT). Unfortunately, there is no document certifying the duration of this interim storage.

On 5 January 2021, Sogin published the National Map of the Potentially Suitable Areas (CNAPI) and a draft outline plan of the Repository and its research center, called "Technology Park", with all the related documentation [25]. In the CNAPI proposal [26], 67 sites were identified using the localization criteria proposed by the Italian Institute for Environmental Protection and Research (ISPRA) in Technical Guide no. 29 [27].

After the publication of the CNAPI and a draft outline plan, a 180-day public consultation phase was carried out in order to share, analyze and discuss the various aspects related to the CNAPI proposal and the Repository's construction [28]. Consequently, Sogin collected all observations formally transmitted by the regions, local authorities and qualified stakeholders and drafted the proposal for the National Map of the Suitable Areas (CNAI). Sogin sent the CNAI proposal to the Ministry of Economic Development (MiSE) and then to the Ministry of the Environment and Energy Security (MASE). The latter proceeded to publish the CNAI proposal on 13 December 2023 [29] after attaining technical clearance from the supervisory body, namely the National Inspectorate for Nuclear Safety and Radiation Protection (ISIN). Sixteen sites were removed from CNAI as compared to CNAPI to take into account the formally transmitted observations that were deemed valid by Sogin, and therefore 51 sites are considered suitable but without a priority order.

The selection procedures for Italian and foreign nuclear sites take place in different steps that progressively narrow the search area as information about a potential site becomes increasingly detailed. Multi-criteria evaluations are often part of these procedures, but none of them can computationally integrate contradictory criteria and their multi-dimensional interdependencies. The latter are crucial to identify optimal solutions within a set of possible alternatives because they allow us to find the best compromise with respect to all the criteria considered in each single step of a selection procedure. To this aim, Multi-Criteria Decision-Making (MCDM) methods offer a different approach that may be beneficial to support a transparent and science-based evaluation of potential sites. In recent years, these methods have experienced significant growth in civil engineering applications to establish criteria weights, vulnerability indices and suitability orders among alternatives. A comprehensive literature review on the topic can be found, for example, in a recent study [30].

The proposed multi-criteria approach compares the 51 sites of the CNAI proposal by analyzing their main short- and long-term risks through a risk index calculated for different decision-making processes according to seismic, logistical and socio-economic criteria and corresponding consistent weights. A different priority order of the CNAI sites is obtained depending on the criteria considered. In Section 2, technical details about the National Repository and the official criteria used for its location are collected and analyzed, and in Section 3, the methodological approach is described and applied. The obtained results are presented and discussed in Section 4, and the main conclusions are drawn in Section 5.

## 2. The National Repository and the Official Criteria for Its Location

The problem of selecting suitable sites for nuclear repositories is a relevant and very current issue in various contexts, especially in Europe, which is generally characterized by a high level of territory anthropization and by strict environmental protection constraints. In this regard, the guidelines published by the International Atomic Energy Agency (IAEA) [31], "Site Survey and Site Selection for Nuclear Installations" (SSG-35), are a useful reference for the homogenization of the procedures to be used for temporary storage facilities. The approaches used are often different, but it is interesting to note that multi-criteria methods are often the basis of evaluations from an international perspective.

For example, Sweden and Finland are world pioneers in finding a permanent solution for high-level radioactive waste in deep geological repositories [32]. After decades of research into geological conditions, Finland will soon host the world's first permanent site on Olkiluoto Island [33]. Germany has officially approved a near-surface repository for low- and medium-level radioactive waste in the Schacht Konrad (i.e., a disused iron mine near Salzgitter). Since 2007, the Konrad repository has been under construction and—after significant delays due in part to protests—its operations are expected to begin in 2027 [34]. The site selection procedure for a DNPT in Germany began in 2017 and should be finalized by 2031. As a first step, in 2020, ninety sub-areas were identified in almost all German federal states by applying exclusion criteria, minimum requirements and geoscientific weighing criteria (for further details, see [34,35]).

In Italy, the Repository and its Technology Park will be designed and constructed following the most recent IAEA standards and the best international practices [25,31–37]. As indicated in the draft outline plan [38], the entire construction will occupy an area of 1.50 $km^2$:1.10 $km^2$ is dedicated to the Repository and 0.40 $km^2$ to the Technology Park. The entire construction phase is estimated to take four years, resulting in significant overall employment benefits [39]. During the operation phase of these infrastructure facilities, direct employment is estimated on average at around 700 employees, with related activities that may increase employment up to around 1000 workers [39]. More specifically, the Repository will be an environmental surface facility capable of hosting approximately 78,000 cubic meters of very-low- and low-level radioactive waste for the next 300 years, as well as approximately 17,000 cubic meters of intermediate- and high-level radioactive waste for an undefined duration until a DNPT is built in a place that has not yet identified [40].

Given that, by 12 March 2024, no self-candidacies were presented by the municipalities excluded from the CNAI proposal and by the Italian Ministry of Defense for relevant military sites, as required by Legislative Decree 31/2010 [23], the identification of the site where to build the Repository continues with the Strategic Environmental Assessment (VAS) procedure [41] on the sites in the CNAI proposal. This procedure should be started by MASE with the technical support of Sogin. At the end of the VAS procedure, Sogin will update the CNAI proposal with the relevant order of suitability. This final version of CNAI should be sent back to the MASE, which will incorporate the ISIN's technical opinion and subsequently approve it with its own decree, in agreement with the Ministry of Infrastructure and Transport (MIT).

Subsequently, in compliance with Legislative Decree 31/2010 [23], Sogin will start bilateral negotiations with the regions and local authorities included in the final CNAI and will define nonbinding agreements with the latter. Within 15 months of the definition of these agreements, Sogin will carry out site investigations in order to formulate a localization proposal to the MiSE. Within the following thirty days, the MiSE in agreement with the MIT and the Ministry of the Environment, Land and Sea will identify, with its own decree, the site for the construction of the Repository after having consulted the Minister of Education, University and Research for the relevant aspects to the research activity. With this same decree, the chosen site will be declared of national strategic interest and will be subject to specific forms of monitoring and protection [23].

According to the information disclosed by Sogin [42], there are approximately three years left until the identification of the Repository site is completed. Once the site is identified, two years will be needed for the final design, five years for construction and a time that is currently undefined will be required for the operating authorizations. Consequently, it is possible to deduce that in addition to the approximately 37 years since the 1987 referendums, the allocation of all Italian radioactive waste in safe long-term storage and its disposal will take at least another 10 years.

After its site investigations, Sogin will formulate the localization proposal of where to build the Repository, trying to maximize the site's safety criteria and the economic benefits for the surrounding population. This is in line with the instructions of Legislative Decree 31/2010 [23] and the IAEA guidelines [37].

Article 27 of Legislative Decree 31/2010 establishes that the suitability order of sites should be obtained on the basis of their technical, economic, environmental and social characteristics. According to IAEA guidelines, site investigations to locate a radioactive waste disposal facility should progress from generalized studies to more detailed characterizations aimed at determining how the site will behave in the long term with respect to the potential effects of seismicity, flooding, erosion and other destructive processes. These effects are an important part of the site characterization process [37].

In the definition of the CNAPI proposal, 15 exclusion criteria (CE1-CE15) together with another 13 criteria for in-depth analysis (specification criteria, CA1-CA13) were applied at a national scale. All these criteria are deducible from the ISPRA Technical Guide no. 29 [27]. They consider the following aspects: (i) natural and anthropogenic hazards; (ii) land use and its height; (iii) distance from cities, coastlines and main infrastructure; (iv) chemical, physical–mechanical, hydrological, geological and geomorphological features; (v) preservation of cultural heritage, typical and high-quality agricultural products, underground natural resources, habitats, geosites and protected flora and fauna species.

The exclusion criteria played a key role in defining the CNAPI proposal. The compliance of a territorial area with an exclusion criterion entailed its direct exclusion from potentially suitable areas. Such criteria are based on official geographical data available for the entire national territory also through the use of Geographic Information Systems (GISs). On the other hand, the specification criteria were used following the application of exclusion criteria. They were defined to accomplish the suitability order of sites and confirm the absence of any exclusion elements that could not be verified during the previous application of exclusion criteria. However, some significant anomalies were highlighted in the application of exclusion and specification criteria and their corresponding results [43].

Among the various exclusion criteria, the seismic criterion CE2 excludes all territorial areas with a Peak Ground Acceleration (PGA, i.e., the maximum ground acceleration that occurred during an earthquake with a given return period) value at the outcropping engineering bedrock equal to or greater than 0.25 g for a 2475-year return period. Although the importance of subsequent seismic site response analysis is already highlighted in this criterion and in the specification criterion CA3 (for more details, see [27]), the results of local site response analyses were not considered in the exclusion of the territorial areas. The implications of these missed assessments play a key role in the present study.

In accordance with Article 27 of Legislative Decree 31/2010, the 67 sites of the CNAPI proposal were ranked into four classes with a decreasing order of suitability (A1—very good continental area, A2—good continental area, B—insular area, C—area in "seismic zone 2") considering socio-environmental, logistical and seismic aspects. The latter are based on the past seismic classification of Italian municipalities introduced by the Ordinance of the President of the Council of Ministers (OPCM) 3274/2003 [44], which divided the entire Italian territory into four homogeneous seismic zones (from 1 to 4, with decreasing hazard levels) and assigned them a corresponding PGA value at the outcropping engineering bedrock with a 475-year return period.

Earthquakes are one of the most disastrous natural events in the world in terms of human life and economic losses [45,46]. In addition, they trigger major nuclear accidents due to natural causes (i.e., [18]). Disasters due to floods, inundation, erosive phenomena and landslides are often caused by human activities and therefore by deforestation, global warming and inadequate distances between the natural limits of a territory (e.g., watercourses, floodplains, wooded areas, high slope reliefs, etc.) and constructions. Conversely, earthquakes are unpredictable natural phenomena that re-originate in seismogenic zones and propagate over vast surrounding areas.

Italy is one of the ten most earthquake-prone countries in the world [47]. In the last two centuries, it has suffered more than 60 destructive earthquakes [48]. Italian seismicity is relatively moderate. According to the CPTI15 catalog [49], on average, 12–20 events with $M_{wp} \geq 6$ occur each century. Moreover, the largest reported magnitude is 7.4. However, mainly due to high vulnerability, only from 1968 to 2018 (50 years), earthquakes caused 5100 victims and EUR 211.5 billion euros of economic losses for reconstruction, amounting to 4.2 billion per year [48]. For all these reasons, among the different natural hazards, Sogin most likely defined the suitability order of the 67 sites in the CNAPI proposal considering seismic aspects only, because the remaining natural hazards could be prevented more easily solely through the application of the exclusion criteria. However, these seismic aspects are unable to quantitatively and fully describe the total hazard level of sites.

The 51 sites included in the resulting CNAI proposal are mapped in Figure 1, together with the nine nuclear facilities managed by Sogin (four nuclear power plants, four nuclear fuel production and research facilities and the ISPRA-1 reactor). As can be deduced from Figure 1, 1 site is located in the Apulia region, 4 sites fall on the border between the Apulia and Basilicata regions, 10 sites fall entirely in the Basilicata region, 21 sites are located in the Latium region, 5 sites are within the Piedmont region, 8 sites are in the Sardinia region and 2 sites are in the Sicily region.

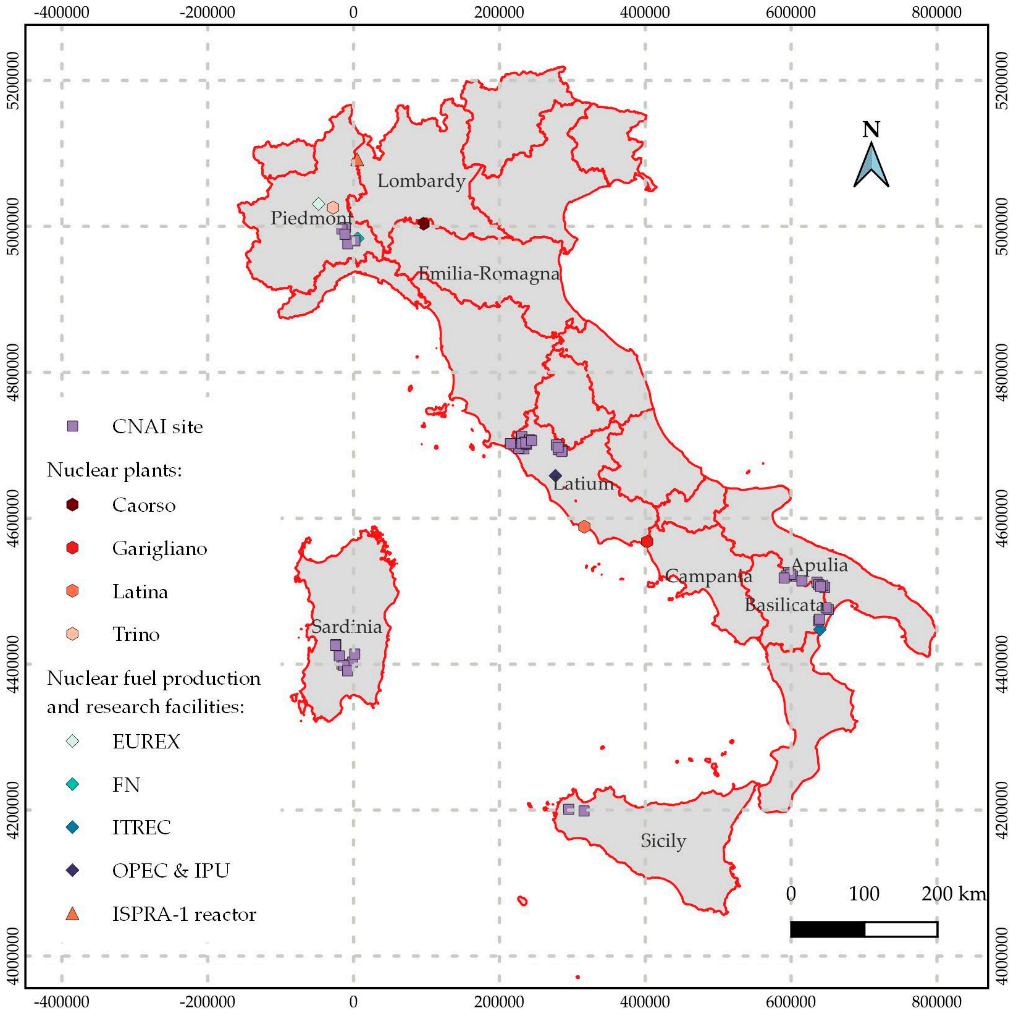


**Figure 1.** Sites included in the CNAI proposal and nuclear facilities managed by Sogin.

## 3. New Proposal for National Repository Location

This section reports on the methodological approach adopted in this study. To enrich the decision-making process with criteria that analyze short- and long-term safety, in addition to the seismic risk assessed on the basis of the total hazard level of sites, other natural risks together with anthropogenic risks and benefits should also be investigated. In this way, Multi-Criteria Decision-Making (MCDM) processes may be developed to achieve better analyses and more robust results. In an MCDM process, the judgment criteria and their weights determine the definitive solution, and if they are explicitly defined, transparency and best practices can also be implemented [50,51]. To this aim, a conceptual scheme of the proposed multi-risk analysis approach is depicted in Figure 2.

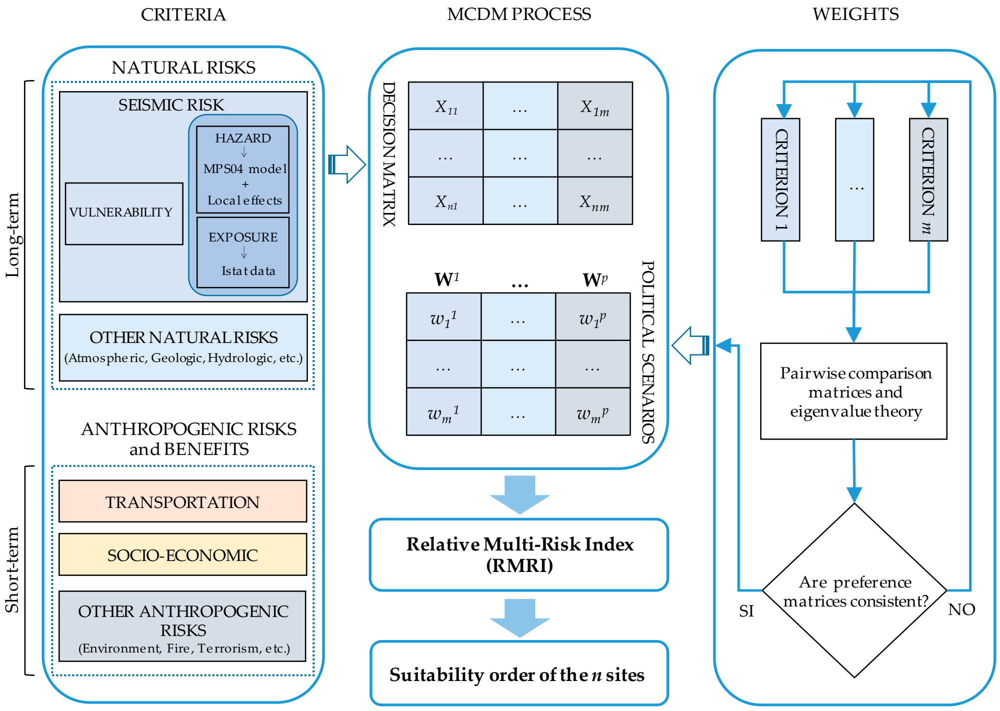


**Figure 2.** Conceptual scheme of the proposed multi-risk-and-benefit analysis to define the suitability order of CNAI sites.

The proposed approach arises from the consideration that the official criteria for the Repository location were not used to combine the different risks and benefits through a multidimensional calculation model. According to the proposed approach, the different natural and anthropogenic risks and/or their components may be quantified independently using a corresponding indicator assessed for each site with a more detailed characterization (left column in Figure 2). Based on the shared choices regarding the criteria and data used, a rectangular decision matrix $n \times m$ ($n$ and $m$ are the number of sites and judgment criteria, respectively) can be obtained by arranging these quantitative indicators in the proper rows and columns.

Multiple criteria weight vectors or political scenarios [51] can be determined by assigning different consistent weights to the considered criteria. A decision-making process based on multiple exclusion criteria or a single judgment criterion does not require a criteria weight definition because, in this case, each criterion has a weight of one hundred percent. On the other hand, in an MCDM process, the analyzed criteria and their hierarchies must be specified in such a way that the sum of the weights of all the criteria is equal to one hundred percent. As a result, countless criteria weight vectors may be defined according to the experience/opinion of qualified operators and the main priorities of policymakers. Hereafter, consistent criteria weight vectors ($W^1, \ldots, W^p$) are generated using pairwise comparison matrices and eigenvalue theory [50,51] in order to obtain a matrix approach that can explicitly take into account the possible uncertainties caused by different scientific and/or political choices (right column in Figure 2).

It is therefore necessary to calculate a final multi-risk index that incorporates the different criteria and weights considered (central column in Figure 2). Thus, CNAI sites can be compared and their suitability order can be defined in a multidimensional and transparent way by ranking the sites from least risky to most risky according to the corresponding multi-risk index value. Obviously, using this approach, any risk and/or benefit can be analyzed separately and aggregated in order to identify the maximum relevance with the considered criteria, which determine the dimensional space of the calculated multi-risk index.

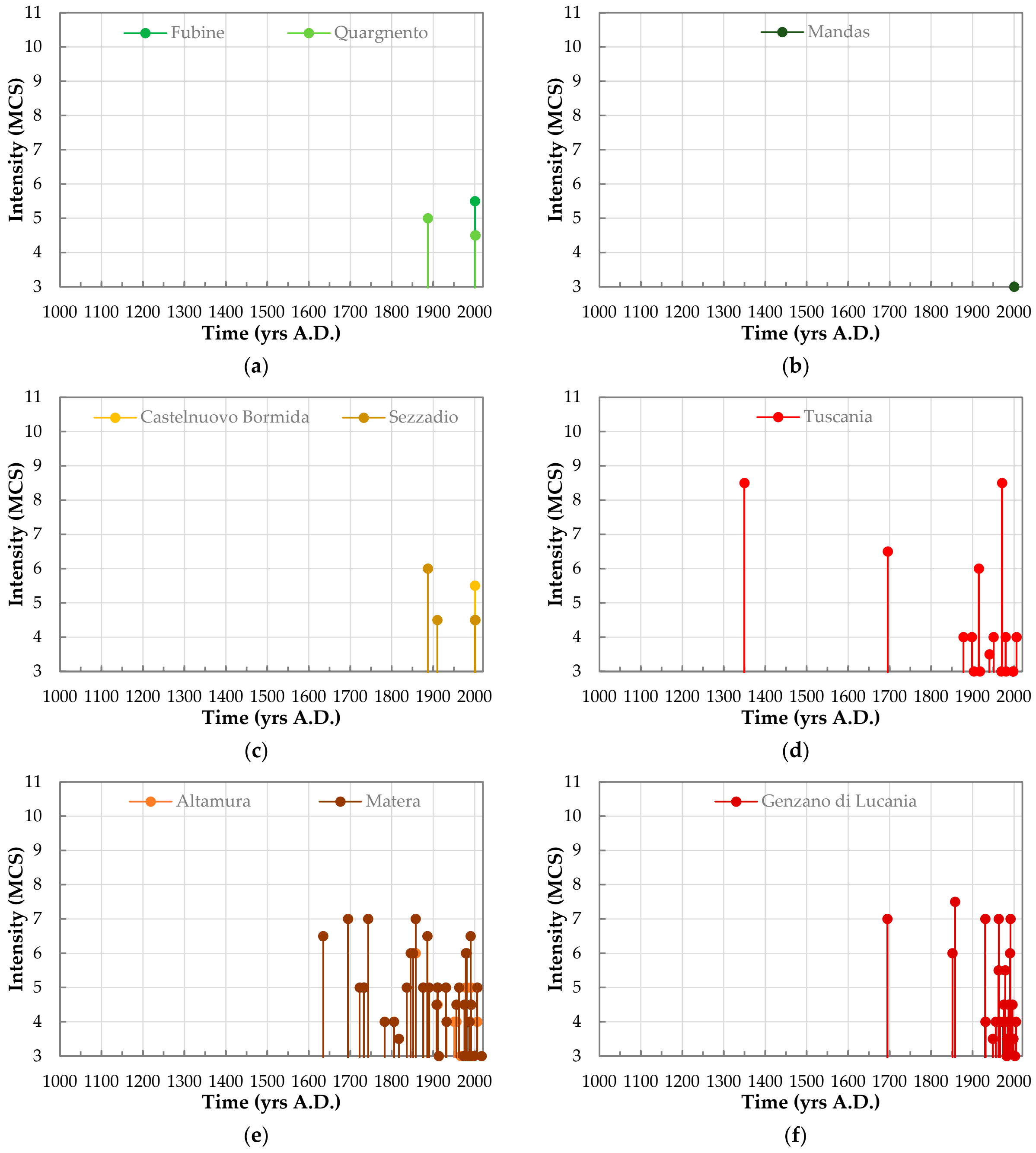
### *3.1. Historical Macroseismic Data, Prospects and Seismic Risk*

First of all, it must be remembered that Italy has one of the most accurate and valuable historical catalogs. The value of the information they contain is very significant and can influence the choice of basic hazard models.

Referring to the Italian Macroseismic Database (DBMI15) [52], Figure 3 shows a comparison between the seismic histories from 1000 to 2020 of some municipalities in whose territories the most suitable and the least suitable sites are located. However, it must be remembered that, although the DBMI15 catalog presents notable improvements compared to previous versions (increase in the number of earthquakes with intensity data and macroseismic observations, Mercalli–Cancani–Sieberg scale, MCS), the increase in observations for the lowest intensities, in particular for intensities between 3 and 5, is essentially due to the inclusion of numerous data relating to moderate-energy events, especially starting in the 19th century. On the one hand, these very-low-intensity earthquakes have little relevance in the classification of the basic seismic hazard; on the other hand, studies and research are still ongoing to improve the analysis of historical data [53]. However, some interesting considerations can be made, especially on sites with medium-high intensity; examples include the following.

- Only very few low-intensity earthquakes are reported for the municipalities where sites AL-14 and AL-13 are located (Figure 3a,c).
- Historically, no significant observations are available for the remaining municipalities to which Sardinia sites belong (Figure 3b).
- High-intensity earthquakes were reported for the municipality of Tuscania (Figure 3d), where in addition to site VT-31, sites VT-25, VT-28, VT-30_A, VT-30_B, VT-32_A, VT-32_B and VT-33 are also included. In particular, Tuscania was devastated by the 1349 Apennine earthquakes and the 1971 Tuscania earthquake, both with a macroseismic intensity value greater than VIII degree.
- Significant seismic activity in terms of the intensity and number of events can be observed for the municipalities of Matera (Figure 3e) and Genzano di Lucania (Figure 3f).

More in detail, the municipality of Matera (sites BA_MT-4 and BA_MT-5 concern the territory of Altamura and Matera) experienced thirty-two seismic events with a macroseismic intensity value greater than III degree, while Genzano di Lucania (in whose territory sites PZ-8, MT_PZ-6, PZ-9, PZ-13 and PZ-14 are included) suffered twenty-six. Among these, three and four earthquakes of the VII degree were recorded in Matera and Genzano di Lucania, respectively. In Genzano di Lucania, the 1857 Basilicata earthquake was even more disastrous, with a macroseismic intensity value greater than VII degree (Figure 3f). This earthquake devastated much of the Basilicata region, causing more than 11,000 deaths. Thus, today, it is very important to understand these fundamental historical aspects in order to build the Repository and the DNPT in a site with the lowest seismic hazard and the least exposure to risks.



(**a**) (**b**) (**c**) (**d**) (**e**) (**f**)

**Figure 3.** Seismic history of (**a**) Fubine and Quargnento, Piedmont region (due to the highest suitability of site AL-14 in the 1st, 2nd and 3rd DMPs); (**b**) all municipalities of Sardinian sites (due to the lowest seismic hazard for a 2475-year return period); (**c**) Castelnuovo Bormida and Sezzadio, Piedmont region (due to the highest suitability of site AL-13 in the 4th DMP); (**d**) Tuscania, Latium region (due to the highest seismic hazard of site VT-31 in the 1st DMP); (**e**) Altamura and Matera, Apulia and Basilicata regions (due to the lowest suitability of site BA_MT-5 in the 2nd, 3rd and 4th DMPs); (**f**) Genzano di Lucania, Basilicata region (due to the highest seismic hazard of site PZ-8 for a 2475-year return period).

As illustrated in Figure 2, a detailed seismic risk assessment may be performed through the convolution of the following components [54]: seismic hazard of site, exposure and vulnerability. In such an assessment, the seismic hazard should necessarily include local site amplification effects [55]. On the other hand, the content of the Repository and its Technology Park, as well as the surrounding population, represent the main exposure factors, while the susceptibility to damage characterizes the structural vulnerability of these infrastructure facilities. Since the vulnerability of the Repository and its content should not vary depending on where it is built, the surrounding population can play a key role in quantifying the seismic risk of the suitable sites. Obviously, the same may be said in a highly populated area without seismic hazard. However, seismic events even of moderate intensity (central Italy, see, for example, [56]) have shown significant effects on communities due to the seismic vulnerability (and consequent damage) of public and private buildings, in particular residential buildings. Effects due to the seismic vulnerability of buildings, which are not homogeneous on the Italian territory, should not be neglected. They have a strong impact on the territory and could affect the operation of the system in post-earthquake emergencies.

In 2022, Italian seismic maps of Amplification Factors (AFs, i.e., the ratio between expected ground motion at the surface and that at the outcropping engineering bedrock) with different percentile values (16th, 50th and 84th) were published for the national territory [57]. These AFs were calculated for PGA and Peak Ground Velocity (PGV, i.e., the maximum speed reached by the ground during an earthquake with a given return period) by considering 630 response spectra related to the 475-year return period and then performing more than 30 million seismic site response analyses. Referring to the 50th percentile of AFs for PGA, the corresponding maximum and minimum value of AFs for PGA may even lead to a doubling (approximately 2.21) or reduction (approximately 0.90) in PGA at the outcropping engineering bedrock, respectively. Consequently, it is essential to take into account the results of site response analyses when assessing the total seismic hazard of sites.

In order to compare all the sites included in the CNAI proposal, the total seismic hazard expressed in terms of acceleration demand ($PGA_D$, i.e., the maximum acceleration at the surface expected for an earthquake with a given return period) of the $i$-th site can be estimated as follows:

$$PGA_{D,i} = PGA_{cen,i} \cdot \frac{\sum_{s=1}^{N} AF_{PGA,is}}{N},\ s \in i \tag{1}$$

where $PGA_{cen,i}$ is the median PGA value (50th percentile) at the outcropping engineering bedrock for a 475-year return period calculated with respect to the centroid of the $i$-th site referring to the grid points of the Italian seismic hazard assessment MPS04 [58,59]; $AF_{PGA,is}$ is the median AF value (50th percentile) for PGA of the $s$-th point of the regular 50 × 50 m grid [57] falling in the $i$-th site; $N$ is the total number of points falling in the $i$-th site. In other words, the last term of Equation (1) is the middle value of all the average amplification factors of the 50 × 50 m grid points that fall in the $i$-th site.

Figure 4 shows an extract of the national map of median AF values for PGA on which the CNAI sites (purple areas with fuchsia circles in their centroids) and MPS04 grid points (yellow circles) are projected using GIS tools. Then, the $PGA_D$ values of CNAI sites are estimated by applying Equation (1) in order to quantify their expected seismic hazard for a 475-year return period.

Since median AF and PGA values reported in their corresponding Italian maps [57,58] are not available for the Sardinia region due to its low seismicity, the maximum $PGA_D$ values of Sardinia sites are calculated according to the current Italian seismic code [59] whose seismic hazard part is grounded on the reference hazard map MPS04 [60]. According to the Italian code, all the municipalities of Sardinia have a PGA value at the outcropping engineering bedrock equal to 0.050 g for a 475-year return period. For soft soils, the corresponding maximum AF value can be set to 1.80 [59] because CNAI sites cannot have a slope greater than 10% due to the application of exclusion criteria and, therefore, the topographic amplification effects can be neglected. As a result, a $PGA_D$ value of 0.090 g is assigned to all CNAI sites in the Sardinia region. This value could also overestimate the results of site-specific analyses that may highlight subsoil categories with lower stratigraphic amplification factors due to more rigid subsoil layers.

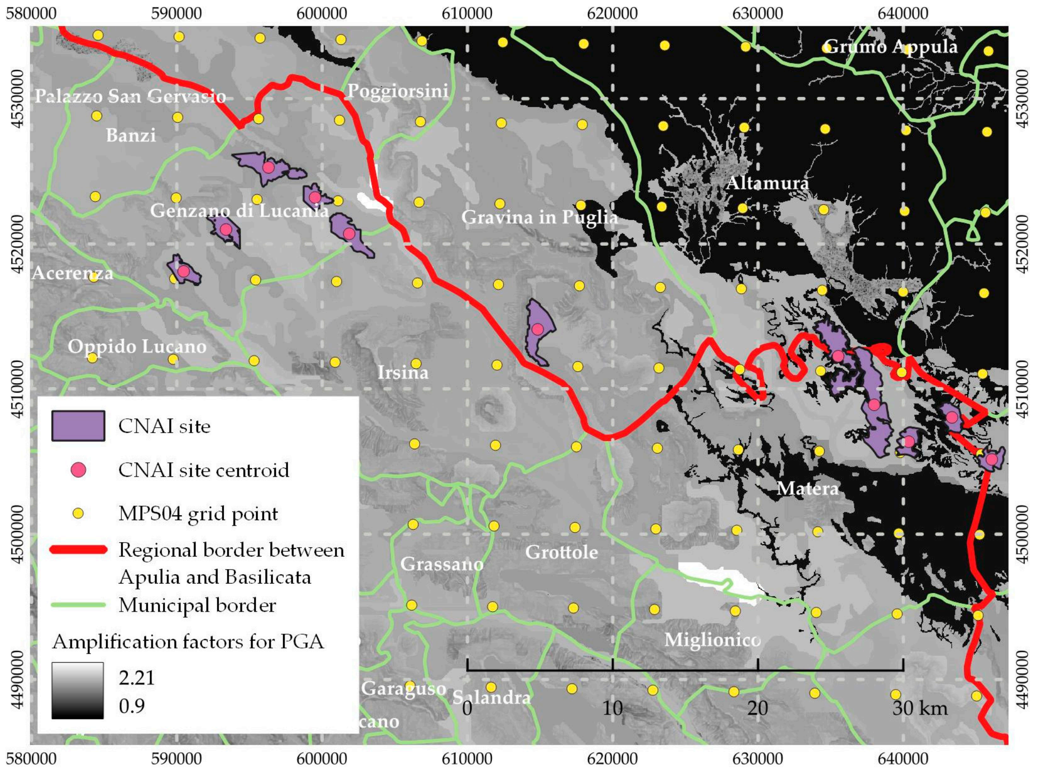


**Figure 4.** Extract of the seismic hazard assessment of CNAI sites for a 475-year return period.

The fifth column of Table 1 (for an optimal synthesis, Table 1 is in the Section 3.4 with all the values calculated as illustrated below) shows the estimated $PGA_D$ values. It is therefore possible to define a first suitability order of CNAI sites by ordering their $PGA_D$ values from lowest to highest. This first order would describe a decision-making process aimed at maximizing only the site's safety criteria in the long term.

It is worthy of note, however, that before any definitive choice, Italy needs a new seismic hazard map to achieve more robust results. A new seismic hazard model was proposed in a recent study [61], but it has not yet been accepted.

Figure 5 shows a comparison between the PGA with 2% probability to be exceeded in 50 years—recently proposed by a working group of expert researchers (see Figure 7c in the original article [61])—with the same quantity [62] that is part of the official Italian hazard database. In Figure 5, the color scale of the official Italian hazard version (on the left) has been modified to match that of the expert working group (on the right) exactly. It is obvious that, even though the general shape of the two maps is similar, the PGA values differ particularly in the areas where the considered sites are located (green ellipses). This can be easily explained: digital instrumental seismology started worldwide about 1976, so even 15 years of higher-quality data are important. Moreover, the previous versions of the historical seismic catalog were not as accurate as the current one, probably differing by about 30%. This is reflected in changes in the overall picture, particularly in the areas considered for the sites. The general criteria for the sites' choice are simple: they should be kept away from seismic areas, which is tantamount to staying away from mountain ranges, and away from areas with large populations and plenty of economic activities, which is tantamount to staying away from plains. Gently hilly transition areas are thus chosen, and these in turn are the ones where the seismic hazard is more difficult to evaluate. It seems, however, obvious that a new, more modern seismic hazard model is necessary, particularly with respect to the definition of a maximum credible earthquake, with a very strong constraint, which is that of totally excluding the presence of active faults nearby.

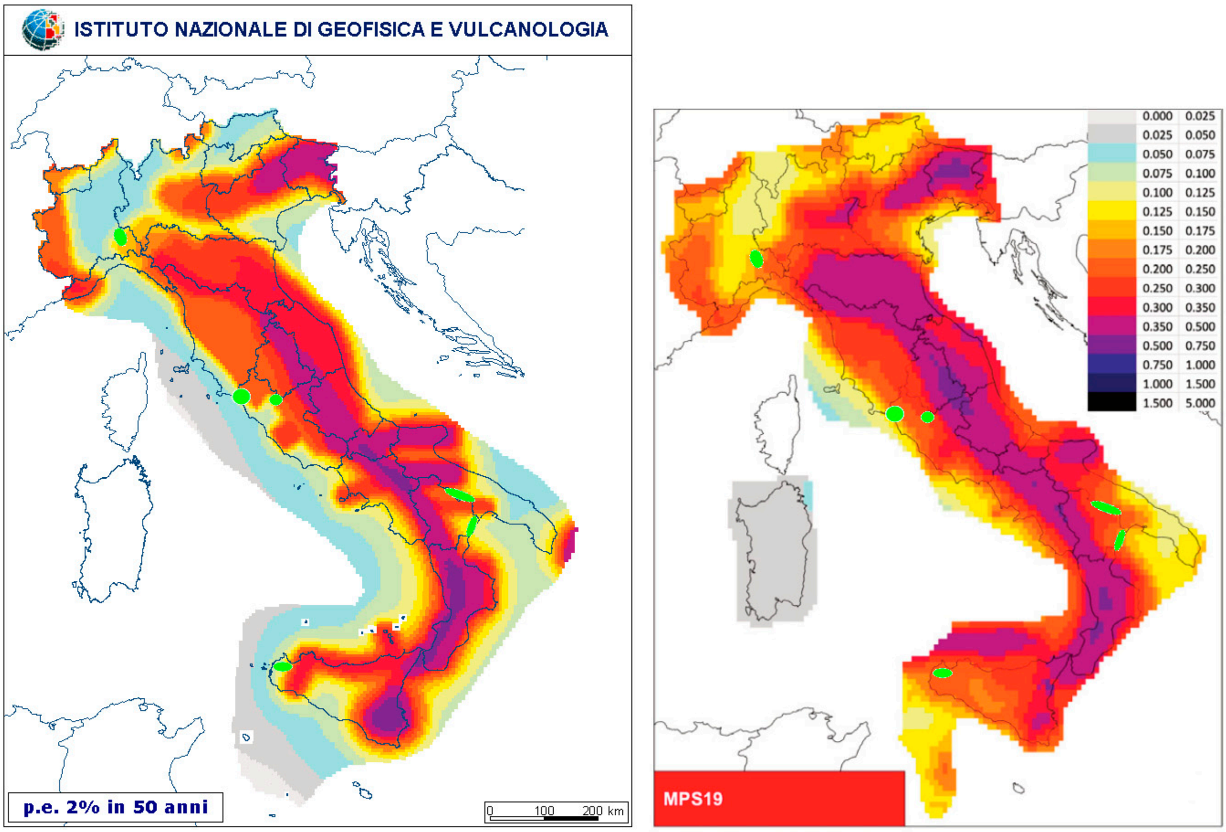


**Figure 5.** Comparison between the PGA with 2% probability to be exceeded in 50 years recently proposed by a working group of expert researchers [62] (**right**) with one with the same quantity that is part of the official Italian hazard database [63] (**left**).

### *3.2. Demographic Data*

The demographic and social–economic data and the potential impact of the Repository on communities are defined on the basis of ISTAT data, that is, the official data that must be used for any planning strategy on the national territory and on the regional territories. ISTAT census data are also used to analyze municipalities with respect to the criteria of integration and social cohesion. Municipal data are taken directly from ISTAT [63]. They are able to take into account the social and economic characteristics of the communities involved. Thanks to these characteristics and the derived criteria, it is possible to investigate the overall socio-economic vulnerability of each community.

The surrounding population is taken into account by assigning to each site its total number of resident population ($P_{TOT,i}$) according to the following equation:

$$P_{TOT,i} = \sum_{d=1}^{M} P(t = 2021)_{id},\ d \in i \qquad (2)$$

where $M$ is the total number of municipalities in whose territory the $i$-th site is included and $P(t = 2021)_{id}$ is the resident population in the $d$-th municipality of the $i$-th site considering the latest 2021 population census data made available by the National Institute of Statistics (ISTAT) [63]. The calculated $P_{TOT}$ values are reported in the sixth column of Table 1. To reduce the exposure factors, the location of the Repository should try to minimize the $P_{TOT}$ values.

### 3.3. Transport Risk

After the operating authorizations, a major short-term risk will be related to the transport of radioactive waste from existing nuclear facilities to the Repository. It is very difficult to quantify this transport risk for each site due to the different space–time aspects involved, but the following time indicator may better capture the relevant hazard, exposure and vulnerability factors:

$$T_{w,i} = \frac{\sum_{f=1}^{F} T_{if} \cdot \sum_{l=1}^{L} I_l \cdot S_{lf}}{\sum_{f=1}^{F} \sum_{l=1}^{L} I_l \cdot S_{lf}} \tag{3}$$

where $T_{w,i}$ is the weighted average travel time of the $i$-th site; $T_{if}$ is the travel time from the $f$-th existing nuclear facility with radioactive waste to the $i$-th site; $I_l$ is used in weighing the relative importance of the $l$-th activity level of radioactive waste; $S_{lf}$ are the cubic meters of radioactive waste with the $l$-th activity level in the $f$-th existing nuclear facility; $F$ is the total number of existing nuclear facility hosting radioactive waste; L is the total number of radioactive waste activity levels.

The indicator of Equation (3) is very useful for analyzing the distance of existing nuclear facilities from each site and the corresponding accessibility of communication routes, as well as the quantities and activity levels of radioactive waste to be transported. As a first attempt, Equation (3) is applied to each CNAI site considering the nine nuclear facilities ($f = 9$) managed by Sogin (Figure 1), for which information on the quantities and activity levels of radioactive waste can be deduced from [10]. In this first attempt, the $T_w$ values are calculated and reported in the seventh column of Table 1 by setting $I = 1.0$ for very-low-, low-, intermediate- and high-level radioactive waste ($L = 4$) in order to avoid arbitrary choices that may alter the data published by Sogin. In siting the Repository, a minimization of the $T_{w,i}$ values should be the objective to reduce transport risks and related costs and emissions. Indeed, decreasing travel times would not only reduce transport costs but also generate environmental benefits in terms of reducing greenhouse gas emissions.

### 3.4. Socio-Economic Risks and Benefits

The Repository's construction will produce economic benefits for the surrounding population. In particular, EUR 1.5 billion will be spent to build the Repository and its Technology Park [64]: EUR 1 billion is expected for the Repository and EUR 500 million for the Technology Park. For a maximum of 5 years, part of this money will therefore generate 4000 workers for their construction. Although these infrastructure facilities will create at least 700 jobs during their full operation, it should be noted that Sogin employs more than one thousand employees [16] to carry out its current tasks, including the managing and decommissioning of the nine existing nuclear facilities. Thus, the Repository will certainly be able to guarantee positive economic benefits for communities near the host site during the construction years. These short-term economic benefits are very useful to counteract the current socio-economic risks (i.e., social degradation, rebellions, school dropout, abandonment of houses and so on) due to the lack of employment opportunities in disadvantaged communities.

To take into account these socio-economic risks and benefits, three practical criteria of integration and social cohesion [65] are derived from ISTAT data and analyzed: (i) unemployment rate (*UR*); (ii) social and material vulnerability (*SMV*); (iii) average population growth rate (*APGR*). Then, the following indicators are assessed for the *i*-th site:

$$UR_i = \frac{\sum_{d=1}^{M} UR(t)_{id} \cdot P(t)_{id}}{\sum_{d=1}^{M} P(t)_{id}},\ d \in i \tag{4}$$

$$SMV_i = \frac{\sum_{d=1}^{M} SMV(t)_{id} \cdot P(t)_{id}}{\sum_{d=1}^{M} P(t)_{id}},\ d \in i \tag{5}$$

$$APGR_i = \frac{\sum_{d=1}^{M} P(t=2021)_{id} - \sum_{d=1}^{M} P(t=2021-\Delta t)_{id}}{\Delta t \cdot \sum_{d=1}^{M} P(t=2021-\Delta t)_{id}},\ d \in i \tag{6}$$

where $UR(t)_{id}$ and $SMV(t=)_{id}$ are the latest *UR* and *SMV* values estimated by ISTAT in 2011 [66] for the *d*-th municipality of each *i*-th site, while $P(t)_{id}$ and $P(t = 2021 - \Delta t)_{id}$ is the corresponding resident population at time instants $t = 2011$ and $t = 2021 - \Delta t$, respectively.

Basically, the *UR* and *SM* indicators of each site are obtained by weighting the $UR(t)_{id}$ and $SMV(t)_{id}$ values of the municipalities involved with respect to their resident population at the same time instant. With reference to the resident population aged at least 15 years, the $UR(t)_{id}$ values are computed by ISTAT at municipal level as a percentage ratio between the number of people seeking employment and the total active population. Likewise, the $SMV(t)_{id}$ values are estimated by ISTAT as a correct arithmetic mean of the normalized values of seven different socio-economic indicators: (i) percentage incidence of the population aged 25–64 who is illiterate or without qualifications; (ii) percentage incidence of families with possible economic poverty; (iii) percentage incidence of families with possible welfare poverty; (iv) percentage incidence of the population living in conditions of severe overcrowding; (v) percentage incidence of families with at least six members; (vi) percentage incidence of single-parent families over the total of families; (vii) percentage incidence of young people aged 15–29 without occupation (study or work). For more details on $UR(t)_{id}$ and $SMV(t)_{id}$ values, see [66,67].

Two ISTAT demographic projections are used in the calculation of *APGR* indicators. As a first attempt, the time elapsed between these two projections is assumed to be 70 years ($\Delta t = 70$ years) in order to analyze a large time interval. Consequently, the 2021 and 1951 ISTAT population census data [68] are taken into account.

The calculated *UR*, *SMV* and *APGR* indicators are reported in the last three columns of Table 1. As can be deduced from the penultimate column of Table 1, the *SMV* values of the sites differ by a few percentage points. Although the correct arithmetic mean may reduce the variability of the $SMV(t)_{id}$ values compared to their individual constituent socio-economic indicators, this reduced variability in *SMV* values highlights that all the communities involved have a comparable economic need to benefit from the immediate economic benefits associated with the Repository's construction. To mitigate socio-economic risks in the short term and thus maximize the immediate economic benefits associated with the Repository's construction, the optimal site should also be identified with the aim of maximizing the *UR* and *SMV* values and minimizing the *APGR* value. In fact, while the highest positive *UR* and *SMV* values recognize the socio-economic vulnerability of communities, the highest negative *APGR* value identifies the site whose communities are currently subject to the highest risk of depopulation.

**Table 1.** CNAI sites and their corresponding risk indicators calculated according to Equations (1)–(6).

| ID | Region | Municipality | Area [km$^2$] | $PGA_D$ [1] [g] | $P_{TOT}$ [2] [inh.] | $T_w$ [3] [Minutes] | $UR$ [4] [%] | $SMV$ [5] [%] | $APGR$ [6] [inh/(inh·Year)] |
|---|---|---|---|---|---|---|---|---|---|
| SU-44 | Sardinia | Segariu, Villamar | 2.13 | 0.090 | 3584 | 901 | 45.74 | 99.41 | −0.0032 |
| OR-60 | Sardinia | Albagiara, Assolo, Mogorella,’Usellus | 3.39 | 0.090 | 1733 | 889 | 43.17 | 99.93 | −0.0078 |
| OR-61 | Sardinia | Albagiara, Usellus | 1.64 | 0.090 | 973 | 889 | 41.34 | 99.46 | −0.0086 |
| SU-31 | Sardinia | Mandas, Siurgus Donigala | 3.39 | 0.090 | 3876 | 922 | 50.17 | 99.59 | −0.0049 |
| SU-45 | Sardinia | Pauli Arbarei, Setzu, Tuili, Turri, Ussaramanna | 6.70 | 0.090 | 2528 | 907 | 40.99 | 100.27 | −0.0076 |
| SU-47 | Sardinia | Nurri | 1.56 | 0.090 | 2034 | 938 | 46.00 | 99.90 | −0.0070 |
| SU-74 | Sardinia | Guasila | 2.41 | 0.090 | 2509 | 906 | 48.00 | 99.40 | −0.0030 |
| SU-73_C | Sardinia | Ortacesus | 3.39 | 0.090 | 883 | 909 | 52.20 | 98.30 | −0.0001 |
| MT_PZ-6 | Basilicata | Genzano di Lucania, Irsina | 3.71 | 0.218 | 9744 | 331 | 49.04 | 99.42 | −0.0068 |
| PZ-8 | Basilicata | Genzano di Lucania | 4.83 | 0.224 | 5303 | 331 | 50.10 | 99.00 | −0.0053 |
| PZ-13 | Basilicata | Genzano di Lucania | 2.86 | 0.228 | 5303 | 331 | 50.10 | 99.00 | −0.0053 |
| PZ-14 | Basilicata | Genzano di Lucania | 2.02 | 0.225 | 5303 | 331 | 50.10 | 99.00 | −0.0053 |
| MT-15 | Basilicata | Bernalda | 6.56 | 0.183 | 11,964 | 348 | 49.90 | 99.40 | 0.0027 |
| MT-16 | Basilicata | Bernalda, Montescaglioso | 6.61 | 0.181 | 21,211 | 348 | 50.26 | 99.22 | 0.0013 |
| BA_MT-4 | Apulia/Bas | Altamura, Matera | 6.15 | 0.191 | 129,603 | 339 | 55.86 | 99.40 | 0.0122 |
| BA_MT-5 | Apulia/Bas | Altamura, Matera | 8.98 | 0.215 | 129,603 | 339 | 55.86 | 99.40 | 0.0122 |
| TA_MT-17 | Apulia/Bas | Laterza, Matera | 2.00 | 0.230 | 74,654 | 344 | 53.28 | 98.99 | 0.0108 |
| TA_MT-18 | Apulia/Bas | Laterza, Matera | 2.16 | 0.206 | 74,654 | 339 | 53.28 | 98.99 | 0.0108 |
| MT-3 | Basilicata | Matera | 2.19 | 0.222 | 59,748 | 339 | 54.30 | 98.70 | 0.0138 |
| PZ-9 | Basilicata | Genzano di Lucania | 2.32 | 0.226 | 5303 | 331 | 50.10 | 99.00 | −0.0053 |
| BA-5 | Apulia | Gravina in Puglia | 4.75 | 0.209 | 42,915 | 331 | 53.00 | 100.40 | 0.0059 |
| TP-9 | Sicily | Calatafimi-Segesta | 2.53 | 0.210 | 6243 | 741 | 47.50 | 99.50 | −0.0066 |
| TP-11 | Sicily | Trapani | 2.05 | 0.120 | 56,293 | 748 | 47.50 | 100.90 | −0.0033 |
| VT-8 | Latium | Montalto di Castro | 2.96 | 0.154 | 8795 | 271 | 58.10 | 99.20 | 0.0225 |
| VT-9 | Latium | Canino, Cellere, Ischia di Castro | 7.08 | 0.239 | 8352 | 289 | 53.64 | 99.86 | −0.0023 |
| VT-24 | Latium | Canino, Montalto di Castro | 4.58 | 0.193 | 13,884 | 286 | 56.97 | 99.43 | 0.0109 |
| VT-25 | Latium | Tarquinia, Tuscania | 3.61 | 0.200 | 24,317 | 272 | 54.93 | 99.07 | 0.0057 |
| VT-26 | Latium | Canino | 4.60 | 0.220 | 5089 | 286 | 55.10 | 99.80 | 0.0020 |
| VT-27 | Latium | Canino, Montalto di Castro | 5.93 | 0.169 | 13,884 | 271 | 56.97 | 99.43 | 0.0109 |
| VT-28 | Latium | Arlena di Castro, Tuscania | 2.95 | 0.251 | 9069 | 281 | 54.58 | 98.96 | 0.0024 |
| VT-29 | Latium | Ischia di Castro | 3.35 | 0.243 | 2188 | 290 | 53.20 | 99.80 | −0.0045 |
| VT-30_A | Latium | Arlena di Castro, Piansano, Tuscania | 3.23 | 0.250 | 10,955 | 281 | 54.43 | 99.03 | 0.0004 |
| VT-30_B | Latium | Piansano, Tuscania | 1.85 | 0.251 | 10,128 | 281 | 54.27 | 99.06 | 0.0006 |
| VT-32_A | Latium | Arlena di Castro, Tessennano, Tuscania | 3.19 | 0.239 | 9357 | 294 | 54.36 | 98.97 | 0.0013 |
| VT-33 | Latium | Tessennano, Tuscania | 2.53 | 0.237 | 8530 | 294 | 54.17 | 99.01 | 0.0016 |
| VT-34 | Latium | Canino | 6.29 | 0.217 | 5089 | 286 | 55.10 | 99.80 | 0.0020 |
| VT-36 | Latium | Montalto di Castro | 2.09 | 0.150 | 8795 | 271 | 58.10 | 99.20 | 0.0225 |
| VT-32_B | Latium | Arlena di Castro, Tuscania | 1.78 | 0.240 | 9069 | 289 | 54.58 | 98.96 | 0.0024 |
| AL-1 | Piedmont | Bosco Marengo, Novi Ligure | 3.87 | 0.151 | 29,690 | 333 | 53.56 | 99.37 | 0.0024 |
| AL-13 | Piedmont | Castelnuovo Bormida, Sezzadio | 4.69 | 0.136 | 1786 | 341 | 55.10 | 98.95 | −0.0086 |
| AL-8 | Piedmont | Alessandria, Castelletto Monferrato, Quargnento | 8.28 | 0.099 | 93,615 | 337 | 54.19 | 98.84 | 0.0015 |
| AL-14 | Piedmont | Fubine, Quargnento | 2.35 | 0.088 | 2924 | 337 | 57.13 | 98.83 | −0.0039 |
| AL-3 | Piedmont | Alessandria, Oviglio | 1.84 | 0.111 | 92,021 | 334 | 54.10 | 98.89 | 0.0014 |
| VT-31 | Latium | Tuscania | 2.05 | 0.252 | 8242 | 281 | 54.40 | 99.00 | 0.0029 |
| VT-11 | Latium | Soriano nel Cimino, Vasanello, Vignanello | 3.10 | 0.220 | 16,299 | 272 | 53.96 | 99.04 | −0.0008 |
| VT-12 | Latium | Corchiano, Vignanello | 4.20 | 0.202 | 7893 | 273 | 53.87 | 99.46 | −0.0005 |
| VT-15 | Latium | Corchiano, Gallese | 4.56 | 0.225 | 6217 | 269 | 56.22 | 99.22 | 0.0031 |
| VT-16 | Latium | Corchiano | 1.95 | 0.221 | 3594 | 273 | 56.80 | 99.40 | 0.0080 |
| VT-20 | Latium | Gallese, Vignanello | 1.95 | 0.217 | 6922 | 269 | 53.09 | 99.31 | −0.0029 |
| MT-1 | Basilicata | Montalbano Jonico | 2.20 | 0.148 | 6796 | 354 | 46.30 | 100.00 | −0.0043 |
| MT-2 | Basilicata | Montalbano Jonico | 4.41 | 0.153 | 6796 | 354 | 46.30 | 100.00 | −0.0043 |

[1] Maximum acceleration at the surface expected for an earthquake with 475-year return period (Equation (1)); [2] total number of resident population (Equation (2)); [3] weighted average travel time (Equation (3)); [4] unemployment rate (Equation (4)); [5] social and material vulnerability (Equation (5)); [6] average population growth rate (Equation (6)).

### 3.5. Decision-Making Processes

In addition to a first decision-making process based solely on the seismic hazard of the sites (second column of Table 2), three different MCDM processes are also implemented. In the second decision-making process (third from last group of columns in Table 2), three judgment criteria are considered: (i) seismic hazard of sites (i.e., $PGA_D$ values), (ii) their exposure (i.e., $P_{TOT}$ values) and (iii) their transport risk (i.e., $T_w$ values). In the third decision-making process (penultimate group of columns in Table 2), transport risk is grouped together with socio-economic criteria (i.e., *ER*, *SMV* and *APGR* values) in order to consider all short-term risks and benefits and thus avoid an excessive influence of transport risk on the suitability order of sites. Finally, in the fourth decision-making process (last group of columns in Table 2), exposure, transport risk and socio-economic criteria are processed. This last decision-making process aims to maximize socio-economic risks and benefits while completely disregarding seismic hazards and therefore long-term site safety.

**Table 2.** Criteria weight vectors ($W^1, \ldots, W^p$) in decision-making processes (DMPs).

| W | 1st DMP | 2nd DMP | | | 3rd DMP | | | | | | 4th DMP | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $PGA_D$ | $PGA_D$ | $P_{TOT}$ | $T_w$ | $PGA_D$ | $P_{TOT}$ | $T_w$ | *UR* | *SMV* | *APGR* | $P_{TOT}$ | $T_w$ | *UR* | *SMV* | *APGR* |
| | $w_1$ | $w_1$ | $w_2$ | $w_3$ | $w_1$ | $w_2$ | $w_3$ | $w_4$ | $w_5$ | $w_6$ | $w_1$ | $w_2$ | $w_3$ | $w_4$ | $w_5$ |
| 1 | 1.000 | 0.540 | 0.297 | 0.163 | 0.540 | 0.297 | 0.041 | 0.041 | 0.041 | 0.041 | 0.540 | 0.297 | 0.054 | 0.054 | 0.054 |
| 2 | | 0.540 | 0.163 | 0.297 | 0.540 | 0.163 | 0.074 | 0.074 | 0.074 | 0.074 | 0.540 | 0.163 | 0.099 | 0.099 | 0.099 |
| 3 | | 0.637 | 0.258 | 0.105 | 0.637 | 0.258 | 0.026 | 0.026 | 0.026 | 0.026 | 0.637 | 0.258 | 0.035 | 0.035 | 0.035 |
| 4 | | 0.637 | 0.105 | 0.258 | 0.637 | 0.105 | 0.065 | 0.065 | 0.065 | 0.065 | 0.637 | 0.105 | 0.086 | 0.086 | 0.086 |
| 5 | | 0.659 | 0.263 | 0.079 | 0.659 | 0.263 | 0.020 | 0.020 | 0.020 | 0.020 | 0.659 | 0.263 | 0.026 | 0.026 | 0.026 |
| 6 | | 0.659 | 0.079 | 0.263 | 0.659 | 0.079 | 0.066 | 0.066 | 0.066 | 0.066 | 0.659 | 0.079 | 0.088 | 0.088 | 0.088 |
| 7 | | 0.717 | 0.217 | 0.066 | 0.717 | 0.217 | 0.016 | 0.016 | 0.016 | 0.016 | 0.717 | 0.217 | 0.022 | 0.022 | 0.022 |
| 8 | | 0.717 | 0.066 | 0.217 | 0.717 | 0.066 | 0.054 | 0.054 | 0.054 | 0.054 | 0.717 | 0.066 | 0.072 | 0.072 | 0.072 |
| 9 | | 0.751 | 0.178 | 0.070 | 0.751 | 0.178 | 0.018 | 0.018 | 0.018 | 0.018 | 0.751 | 0.178 | 0.023 | 0.023 | 0.023 |
| 10 | | 0.751 | 0.070 | 0.178 | 0.751 | 0.070 | 0.045 | 0.045 | 0.045 | 0.045 | 0.751 | 0.070 | 0.059 | 0.059 | 0.059 |
| 11 | | 0.818 | 0.091 | 0.091 | 0.818 | 0.091 | 0.023 | 0.023 | 0.023 | 0.023 | 0.818 | 0.091 | 0.030 | 0.030 | 0.030 |
| 12 | | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 13 | | 0.297 | 0.540 | 0.163 | 0.297 | 0.540 | 0.041 | 0.041 | 0.041 | 0.041 | 0.297 | 0.540 | 0.054 | 0.054 | 0.054 |
| 14 | | 0.163 | 0.540 | 0.297 | 0.163 | 0.540 | 0.074 | 0.074 | 0.074 | 0.074 | 0.163 | 0.540 | 0.099 | 0.099 | 0.099 |
| 15 | | 0.258 | 0.637 | 0.105 | 0.258 | 0.637 | 0.026 | 0.026 | 0.026 | 0.026 | 0.258 | 0.637 | 0.035 | 0.035 | 0.035 |
| 16 | | 0.105 | 0.637 | 0.258 | 0.105 | 0.637 | 0.065 | 0.065 | 0.065 | 0.065 | 0.105 | 0.637 | 0.086 | 0.086 | 0.086 |
| 17 | | 0.263 | 0.659 | 0.079 | 0.263 | 0.659 | 0.020 | 0.020 | 0.020 | 0.020 | 0.263 | 0.659 | 0.026 | 0.026 | 0.026 |
| 18 | | 0.079 | 0.659 | 0.263 | 0.079 | 0.659 | 0.066 | 0.066 | 0.066 | 0.066 | 0.079 | 0.659 | 0.088 | 0.088 | 0.088 |
| 19 | | 0.217 | 0.717 | 0.066 | 0.217 | 0.717 | 0.016 | 0.016 | 0.016 | 0.016 | 0.217 | 0.717 | 0.022 | 0.022 | 0.022 |
| 20 | | 0.066 | 0.717 | 0.217 | 0.066 | 0.717 | 0.054 | 0.054 | 0.054 | 0.054 | 0.066 | 0.717 | 0.072 | 0.072 | 0.072 |
| 21 | | 0.178 | 0.751 | 0.070 | 0.178 | 0.751 | 0.018 | 0.018 | 0.018 | 0.018 | 0.178 | 0.751 | 0.023 | 0.023 | 0.023 |
| 22 | | 0.070 | 0.751 | 0.178 | 0.070 | 0.751 | 0.045 | 0.045 | 0.045 | 0.045 | 0.070 | 0.751 | 0.059 | 0.059 | 0.059 |
| 23 | | 0.091 | 0.818 | 0.091 | 0.091 | 0.818 | 0.023 | 0.023 | 0.023 | 0.023 | 0.091 | 0.818 | 0.030 | 0.030 | 0.030 |
| 24 | | 0.000 | 1.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 |
| 25 | | 0.297 | 0.163 | 0.540 | 0.297 | 0.163 | 0.135 | 0.135 | 0.135 | 0.135 | 0.297 | 0.163 | 0.180 | 0.180 | 0.180 |
| 26 | | 0.163 | 0.297 | 0.540 | 0.163 | 0.297 | 0.135 | 0.135 | 0.135 | 0.135 | 0.163 | 0.297 | 0.180 | 0.180 | 0.180 |
| 27 | | 0.258 | 0.105 | 0.637 | 0.258 | 0.105 | 0.159 | 0.159 | 0.159 | 0.159 | 0.258 | 0.105 | 0.212 | 0.212 | 0.212 |
| 28 | | 0.105 | 0.258 | 0.637 | 0.105 | 0.258 | 0.159 | 0.159 | 0.159 | 0.159 | 0.105 | 0.258 | 0.212 | 0.212 | 0.212 |
| 29 | | 0.263 | 0.079 | 0.659 | 0.263 | 0.079 | 0.165 | 0.165 | 0.165 | 0.165 | 0.263 | 0.079 | 0.220 | 0.220 | 0.220 |
| 30 | | 0.079 | 0.263 | 0.659 | 0.079 | 0.263 | 0.165 | 0.165 | 0.165 | 0.165 | 0.079 | 0.263 | 0.220 | 0.220 | 0.220 |
| 31 | | 0.217 | 0.066 | 0.717 | 0.217 | 0.066 | 0.179 | 0.179 | 0.179 | 0.179 | 0.217 | 0.066 | 0.239 | 0.239 | 0.239 |
| 32 | | 0.066 | 0.217 | 0.717 | 0.066 | 0.217 | 0.179 | 0.179 | 0.179 | 0.179 | 0.066 | 0.217 | 0.239 | 0.239 | 0.239 |
| 33 | | 0.178 | 0.070 | 0.751 | 0.178 | 0.070 | 0.188 | 0.188 | 0.188 | 0.188 | 0.178 | 0.070 | 0.250 | 0.250 | 0.250 |
| 34 | | 0.070 | 0.178 | 0.751 | 0.070 | 0.178 | 0.188 | 0.188 | 0.188 | 0.188 | 0.070 | 0.178 | 0.250 | 0.250 | 0.250 |
| 35 | | 0.091 | 0.091 | 0.818 | 0.091 | 0.091 | 0.205 | 0.205 | 0.205 | 0.205 | 0.091 | 0.091 | 0.273 | 0.273 | 0.273 |
| 36 | | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.250 | 0.250 | 0.250 | 0.250 | 0.000 | 0.000 | 0.333 | 0.333 | 0.333 |
| 37 | | 0.333 | 0.333 | 0.333 | 0.333 | 0.333 | 0.083 | 0.083 | 0.083 | 0.083 | 0.333 | 0.333 | 0.111 | 0.111 | 0.111 |

For each decision-making process, the corresponding decision matrix is constructed by inserting the site values reported in Table 1 into the column relating to each *j*-th judgment criterion specified in Table 2. All matrices have 51 rows (i.e., the total number of CNAI sites) and a number of columns that depends on the number of judgment criteria analyzed in the decision-making process.

To consider possible political choices and their uncertainties and avoid bias in defining the criteria weight, thirty-seven criteria weight vectors are implemented for each MCDM process by using an existing procedure [50] that is able to evaluate criteria weight according to the consistent comparisons of three main criteria groups. In this procedure, 3 × 3 preference matrixes were constructed with simple binary comparisons between the analyzed criteria groups. Then, thirty-four criteria weight vectors were obtained according to the principal eigenvectors and eigenvalues of these preference matrixes. More specifically, this total number of criteria weight vectors is due to the consistency check performed using the principal eigenvalue of each preference matrix. In principle, such a consistency check aims to exclude unacceptable conflicts in the definition of preference matrices. Additionally, three criteria weight vectors were defined by assigning a weight of one hundred percent to each criteria group. Consequently, thirty-seven criteria weight vectors were developed by varying the weight of the criteria groups between zero and one (for more details, see [51]). Starting from these main results, the third last group of columns in Table 2 shows all the components calculated for the thirty-seven criteria weight vectors of each MCDM process. In each one, the following can be deduced from Table 2: the first twelve criteria weight vectors attribute greater importance to the first criterion, the second twelve place more emphasis on the second criterion, the third twelve emphasize the importance of the last criterion (or criteria group in the case of the third and fourth decision-making processes, where the weights are uniformly distributed in the criteria group) and, finally, the last vector gives the same importance to all criteria and/or criteria groups.

Once the decision matrices and their corresponding criteria weight vectors are determined, a Relative Multi-Risk Index of the *i*-th site ($RMRI_i$) is assessed for each MCDM process using the following equation:

$$RMRI_i = \frac{Z_i}{\sum\limits_{i=1}^{n} Z_i} \tag{7}$$

where $Z_i$ is the mean normalized relative closeness of the *i*-th site calculated with all thirty-seven criteria weight vectors of the considered MCDM process using a recent MCDM procedure [69] and $n$ is the total number of CNAI sites (i.e., $n$ = 51 just like the number of rows of each decision matrix). Referring to thirty-seven criteria weight vectors, $Z_i$ was proposed in the aforementioned procedure to calculate a Relative Resilience Index (RRI) whereby economic resources may be distributed among Italian regions with the aim of strengthening the resilience deficiencies of their communities.

For each MCDM process, $Zi$ is evaluated analytically by dividing the sum of the normalized relative distances of each criteria weight vector by the total number of vectors (i.e., thirty-seven). In the $Z_i$ calculation, $PGA_D$, $P_{TOT}$, $T_w$ and $APGR$ are processed as benefit criteria (their maximization is the goal), while $UR$ and $SMV$ are treated as cost criteria (their minimization is the goal). Geometrically, $Z_i$ provides an average measurement over all the analyzed criteria weight vectors of the corresponding normalized relative distances computed in a dimensional space defined by the criteria considered in the different MCDM processes. For more details on $Z_i$ calculation, see [69].

## 4. Results and Discussion

By applying Equations (1)–(7), a suitable order of CNAI sites may be determined for each decision-making process analyzed. Table 3 summarizes the results of the present study. In particular, the second column of Table 3 simply provides the site demand accelerations for the first decision-making process. They are normalized with respect to the corresponding minimum site acceleration. The next three columns contain the *RMRI* values relating to the MCDM processes, while in the penultimate column, the $PGA_D$ values for a return period of 2475 years are also calculated and reported to analyze the CNAI sites over the maximum return period considered in the seismic exclusion criterion CE2 (see Section 2). Moreover, in the last column of Table 3, the same suitability classes established in the previous CNAPI proposal are assigned to the relevant CNAI sites to make some comparisons with the obtained results. The latter are also used to investigate the seismic histories of the municipalities in whose territories the most and least suitable sites are located.

**Table 3.** Results of DMPs, $PGA_D$ values calculated for a 2475-year return period (values less than 0.25 g are highlighted in bold) and suitability order in the CNAPI proposal.

| **ID** | **1st DMP Seismicity Only (TR [1] = 475 Years)** | **2nd DMP Without Socio-economic Criteria** | **3rd DMP All Criteria** | **4th DMP Without Seismicity** | **$PGA_D$_2475 Seismicity Only (TR [1] = 2475 Years)** | **CNAPI Class** |
|---|---|---|---|---|---|---|
| | $PGA_{D,i}/PGA_{D,min}$ | *RMRI* | *RMRI* | *RMRI* | **g** | |
| SU-44 | 1.028 | 0.02403 | 0.00773 | 0.02673 | **0.134** * | B |
| OR-60 | 1.028 | 0.02350 | 0.00625 | 0.02463 | **0.134** * | B |
| OR-61 | 1.028 | 0.02342 | 0.00613 | 0.02448 | **0.134** * | B |
| SU-31 | 1.028 | 0.02453 | 0.00741 | 0.02646 | **0.134** * | B |
| SU-45 | 1.028 | 0.02400 | 0.00658 | 0.02525 | **0.134** * | B |
| SU-47 | 1.028 | 0.02459 | 0.00675 | 0.02588 | **0.134** * | B |
| SU-74 | 1.028 | 0.02399 | 0.00758 | 0.02676 | **0.134** * | B |
| SU-73_C | 1.028 | 0.02387 | 0.00848 | 0.02803 | **0.134** * | B |
| MT_PZ-6 | 2.492 | 0.01408 | 0.01361 | 0.00671 | 0.377 | C |
| PZ-8 | 2.556 | 0.01324 | 0.01319 | 0.00597 | 0.420 ** | C |
| PZ-13 | 2.600 | 0.01346 | 0.01342 | 0.00597 | 0.393 | C |
| PZ-14 | 2.576 | 0.01334 | 0.01330 | 0.00597 | 0.396 | C |
| MT-15 | 2.091 | 0.01303 | 0.01612 | 0.01395 | 0.287 | C |
| MT-16 | 2.068 | 0.01611 | 0.01848 | 0.01636 | 0.285 | C |
| BA_MT-4 | 2.186 | 0.05524 | 0.06356 | 0.06129 | 0.303 | A2 |
| BA_MT-5 | 2.451 | 0.05642 ** | 0.06509 ** | 0.06129 ** | 0.347 | A2 |
| TA_MT-17 | 2.632 | 0.03926 | 0.04581 | 0.04290 | 0.391 | A2 |
| TA_MT-18 | 2.357 | 0.03811 | 0.04472 | 0.04279 | 0.337 | A2 |
| MT-3 | 2.539 | 0.03299 | 0.04060 | 0.03847 | 0.366 | A2 |
| PZ-9 | 2.581 | 0.01336 | 0.01332 | 0.00597 | 0.379 | C |
| BA-5 | 2.388 | 0.02559 | 0.03020 | 0.02726 | 0.340 | A2 |
| TP-9 | 2.394 | 0.02607 | 0.01396 | 0.02131 | 0.390 | C |
| TP-11 | 1.377 | 0.03900 | 0.02821 | 0.04059 | **0.205** | C |
| VT-8 | 1.760 | 0.00822 | 0.02137 | 0.02289 | **0.238** | A1 |
| VT-9 | 2.733 | 0.01398 | 0.01591 | 0.00771 | 0.398 | C |
| VT-24 | 2.211 | 0.01295 | 0.02101 | 0.01857 | 0.318 | A2, C |
| VT-25 | 2.289 | 0.01701 | 0.02258 | 0.01887 | 0.334 | A2, C |
| VT-26 | 2.512 | 0.01198 | 0.01600 | 0.00977 | 0.369 | C |
| VT-27 | 1.929 | 0.01110 | 0.01955 | 0.01840 | 0.268 | A1, C |
| VT-28 | 2.868 | 0.01470 | 0.01867 | 0.01120 | 0.415 | C |
| VT-29 | 2.775 | 0.01287 | 0.01390 | 0.00417 | 0.400 | C |
| VT-30_A | 2.861 | 0.01522 | 0.01828 | 0.01042 | 0.406 | C |
| VT-30_B | 2.871 | 0.01501 | 0.01817 | 0.01027 | 0.406 | C |
| VT-32_A | 2.727 | 0.01432 | 0.01771 | 0.01070 | 0.396 | C |
| VT-33 | 2.711 | 0.01401 | 0.01758 | 0.01069 | 0.393 | C |
| VT-34 | 2.479 | 0.01179 | 0.01584 | 0.00977 | 0.365 | C |
| VT-36 | 1.712 | 0.00790 | 0.02114 | 0.02289 | **0.226** | A1 |
| VT-32_B | 2.742 | 0.01423 | 0.01819 | 0.01131 | 0.397 | C |
| AL-1 | 1.726 | 0.01708 | 0.02028 | 0.01992 | 0.292 | A1 |
| AL-13 | 1.557 | 0.00668 | 0.00503 | 0.00360 * | 0.266 | A2 |
| AL-8 | 1.131 | 0.04024 | 0.04288 | 0.04493 | **0.156** | A1 |
| AL-14 | 1.000 * | 0.00350 * | 0.00373 * | 0.00630 | **0.136** | A1 |
| AL-3 | 1.264 | 0.03999 | 0.04267 | 0.04423 | **0.193** | A1 |
| VT-31 | 2.878 ** | 0.01452 | 0.01874 | 0.01133 | 0.407 | C |
| VT-11 | 2.510 | 0.01523 | 0.01796 | 0.01153 | 0.365 | C |
| VT-12 | 2.309 | 0.01141 | 0.01447 | 0.00861 | 0.335 | A1 |
| VT-15 | 2.570 | 0.01238 | 0.01706 | 0.01075 | 0.378 | C |
| VT-16 | 2.527 | 0.01158 | 0.01860 | 0.01367 | 0.372 | A1 |
| VT-20 | 2.475 | 0.01205 | 0.01402 | 0.00650 | 0.360 | C |
| MT-1 | 1.696 | 0.00924 | 0.00890 | 0.00796 | **0.220** | C |
| MT-2 | 1.751 | 0.00958 | 0.00925 | 0.00796 | **0.227** | C |

[1] Return period; * minimum value within the column; ** maximum value within the column.

Since Sogin's objective is to maximize the site's safety criteria and its economic benefits [42], a suitable order of CNAI sites may be defined by ordering the calculated risk values from lowest to highest. In this manner, the best solution can be identified for each decision-making process. It is the one with the lowest risk in relative terms.

As shown in Table 3, all sites have a risk, but site AL-14 (in the Piedmont region) presents the lowest risk value for the first, second and third decision-making process due to its reduced hazard, exposure and transport risk, as well as its unfavorable socio-economic conditions (see also Table 1). In the first decision-making process, site AL-14 is immediately followed by the Sardinia sites (all with a total seismic hazard greater than 1.028 times that of site AL-14), while site AL-13 (also in the Piedmont region) is the second optimal solution in the second and third decision-making processes, with an *RMRI* value of 0.00668 and 0.00503, respectively. Then, site VT-36 (Latium region) is the third optimal solution in the second decision-making process (*RMRI* = 0.00790), while site OR-61 (Sardinia region) is the third optimal solution in the third process (*RMRI* = 0.00613). Completely neglecting seismic hazards in the fourth decision-making process, site AL-13 is also the most suitable due to its reduced exposure and the highest risk of depopulation (see also sixth and last column of Table 1). It is followed by site VT-29 (in the Latium region, *RMRI* = 0.00417) and site PZ-8 (in the Basilicata region, *RMRI* = 0.00597), both of which have a risk of depopulation.

On the contrary, site VT-31 (in the Latium region) is the least safe in the first decision-making process due to its higher seismic hazard for the 475-year return period, which is 2.878 times that of site AL-14. Site BA_MT-5 (in the Apulia and Basilicata regions) is the least safe in the second, third and fourth decision-making processes. In particular, site BA_MT-5 is always preceded by site BA_MT-4 (also in the Apulia and Basilicata regions), with *RMRI* values of 0.05524, 0.06356 and 0.06129 in the second, third and fourth decision-making process, respectively. This is mainly due to their significant exposure, which is the highest.

However, the suitability orders of sites may change if different choices are made in the site evaluations. For example, considering the last two ISTAT demographic projections (i.e., 2021 [63] and 2011 [66], $\Delta t$ = 10 years) in the calculation of the APGR indicators of Equation (6), sites AL-14 and AL-13 continue to have the lowest risk value for the second decision-making process, because in this case, the transport risk is considered equally comparable to the seismic hazard and exposure. When, in the third decision-making process, the importance of transport risk is reduced to give space to socio-economic risks/benefits, the best solution becomes site OR-60 (Sardinia region) followed by other Sardinian sites due to their low exposure and seismic hazards and their high socio-economic risks (see Table 1). Finally, site VT-20 (Latium region) becomes the best solution in the fourth decision-making process due to its socio-economic risks and its strategic position with respect to the nine nuclear facilities managed by Sogin, which are considered in the transport risk calculation (Equation (3)). It is followed by sites VT-29 and PZ-8, respectively. Again, in the second, third and fourth decision-making processes, site BA_MT-5 continues to be the least safe. It is always preceded by site BA_MT-4.

To compare the seismic hazard of sites for a return period of 2475 years, the corresponding $PGA_D$ values are also calculated using Equation (1) (penultimate column of Table 3). Although the AFs might reduce when the level of acceleration at the outcropping engineering bedrock increases due to the non-linearity of soil behavior [70], the same $AF_{PGA}$ values evaluated for the 475-year return period are used in this last estimation. Such over-approximation is useful for making some important considerations about the application of exclusion criteria to define CNAI sites and the possible location of both the Repository and the DNPT.

If the acceleration threshold value of 0.25 g in the CE2 exclusion criterion [27] had considered the total seismic hazard, the suitable sites would have been much fewer. As can be deduced from the bold values in the last column of Table 3, the following sites would certainly have been included in the CNAI proposal: (i) all sites in the Sardinia region; (ii) TP-11 in the Sicily region; (iii) VT-8 and VT-38 in the Latium region; (iv) AL-3, AL-8 and

AL-14 in the Piedmont region; (v) MT-1 and MT-2 in the Basilicata region. In particular, for a return period of 2475 years, all sites in the Sardinia region have the lowest seismic hazard, while the PZ-8 site in the Basilicata region has the highest seismic hazard. In this case, the latter has a $PGA_D$ value equal to 3.127 times that of the Sardinian sites.

Comparing the results reported in the first six columns of Table 3 with the CNAPI suitability classes (last column of the same table), it is possible to deduce the following.

- In accordance with the CNAPI suitability classes, site AL-14 can be considered a very good solution (class A1) to host the Repository, and sites PZ-8, MT_PZ-6, PZ-8, PZ-13, PZ-14, VT-25, VT-28, VT-30_A, VT-30_B, VT-32_A, VT-32_B and VT-33 can be deemed to have a high seismic hazard (Class C).
- Site AL-13 could be classified as class A1 instead of class A2.
- Sardinia sites could have a suitability class higher than class B, especially if seismic hazard, exposure and socio-economic risks are considered together with transport risk.
- Sites MT-1 and MT-2 could have a suitability class higher than class C because they show a lower seismic hazard than sites in class C (e.g., compare the bold values in Table 3 with the corresponding CNAPI classes). This higher suitability class may not be extended to site TP-11 due to its high exposure and transport risk (see also Table 1).
- Sites BA_MT-4 and site BA_MT-5 cannot be deemed good solutions (class A2) because they are the riskiest from a multi-risk perspective.

As a result, there are some differences between the results of this work and the CNAPI suitability classes. With the exception of the seismic aspects, Sogin did not provide details on the remaining socio-environmental and logistical aspects (see Section 2). Furthermore, it is not clear how all these aspects were processed and whether their interdependencies were taken into account in the attribution of the different CNAPI suitability classes.

The obtained results suggest that the socio-environmental, logistical and seismic aspects considered in the definition of the CNAPI suitability classes were not jointly elaborated using a multidimensional computational model. This can be inferred, for example, from the least suitable class C in the CNAPI proposal, where only a partial component of seismic risk was taken into account completely neglecting the amplification effects. Similarly, the same could be said for the Sardinia sites, which focus mainly on the logistical aspects, or for sites BA_MT-4 and BA_MT-5, where the interdependencies between seismic, transport and socio-economic risks determine the highest risk.

As previously described in Section 2, very-low- and low-level radioactive waste will definitely be hosted in the Repository for at least 300 years, together with intermediate- and high-level radioactive waste for an undefined duration, since a site suitable for DNPT construction has not yet been identified. It would therefore be appropriate to locate the DNPT on the same site as the Repository or on a site close to it in order to solve the problem of disposing of all Italian radioactive waste. In this way, a definitive national solution will be identified. This will avoid new risks and costs for future generations.

Such a solution may be used if a shared European DNPT is not built in a less seismic area than the Italian territory. The latter could be built in the future through an agreement between European countries with limited quantities of intermediate- and high-level radioactive waste in order to permanently dispose of their waste and thus share the high construction costs [71]. However, given the high difficulty in obtaining a shared solution at the national level, it will probably be much more complicated to find a definitive shared solution at the European level. Accordingly, it would be prudent and reasonable already to research the location of the DNPT in conjunction with the Repository.

The service life of a DNPT is very long. It can be up to hundreds of thousands of years [71]. Hence, a DNPT should be built in a stable geological formation without appreciable seismic activity. Furthermore, considering only the degradation of structural and non-structural materials, 300 years is not a short time to guarantee high safety performance of the Repository. It would be unthinkable and unwise to rely only on the reduced vulnerability of the Repository while completely neglecting the seismic hazard of the site. In fact, seismic risk cannot be addressed for hundreds of years simply by maximizing the structural robustness of the Repository. Indeed, if that were the case, it would not have made sense for Sogin to apply the exclusion criteria to obtain the CNAPI and CNAI proposals, because all natural hazards could be overcome with the same flawed logic. For all these reasons, it is essential to locate the Repository while paying close attention to the total seismic hazard of the sites. In particular, it is absolutely necessary to ensure that the considered sites are not placed along an active fault and that there is no risk of soil liquefaction.

## 5. Conclusions

This study presents a multi-risk analysis approach with the aim of enriching the decision-making process regarding the location of the National Repository with useful information and knowledge. The proposed approach relies on existing data and MCDM procedures published by recognized institutions and authors. Based on seismic, transport and socio-economic risks, four decision-making processes are simulated in order to investigate different prioritization objectives. In addition, the total seismic hazard of sites for a 2475-year return period is also estimated. Together with the Sogin site investigations, the obtained results can be very useful for defining a suitable order of the CNAI sites and possibly siting the Repository and DNPT. The following findings are reached.

- The data and criteria considered and their possible combinations and weights can profoundly alter the suitability order of the sites. The possibility of simultaneously taking into account multiple criteria weight vectors in the various MCDM processes allowed us to identify the sites with the best response to the analyzed criteria, reducing the level of subjectivity in the definition of their weights and considering the possible uncertainties within the decision-making process.
- The judgment criteria and the related evaluations and weights should be well defined and made explicit in order to avoid any non-objective and non-scientifically motivated alternative in the choice of the suitable site to host nuclear waste.
- In siting the Repository, possible sites for the DNPT should be considered jointly in order to find a definitive solution to the long-standing issue of Italian nuclear waste disposal and thus avoid new risks and costs for future generations. In particular, the Repository should be located with the vision that the DNPT can be built on the same site or in a site very close to it. For example, this vision may be achieved by subjecting the data available for the CNAI sites to the minimum requirements and geoscientific weighting criteria currently used in the German approach [32,33] to identify a possible site for a DNPT.
- It is necessary to identify the site on which to build the Repository and possibly the DNPT by focusing mainly on the site safety criteria evaluated over their entire service life (or for as long as possible, in the case of the DNPT) and also considering the possible economic advantages in the short term.

The possible location of the sites is defined by neglecting some environmental issues and others related to land use. These issues could be explored and integrated in subsequent research phases, considering more accurate analyses, for example, also taking into account the results of the SEA procedures that will be disseminated by MASE and Sogin. However, new data could be easily combined and processed within the proposed framework to address informed decision-making in a practically convenient and technically valid way, enhancing the auditability and possible conflict resolution necessary to reach consensual agreements. The developed approach could represent a valid support for the planning and implementation of decommissioning programs of the numerous nuclear reactors present in the world that are approaching the end of their service life.

Finally, it should be highlighted that this study aims to have a strong methodological and proactive value. In the proposed study, great emphasis has been given to seismic hazards, both as an example and for their historical relevance (also in recent Italian seismic events). From a conceptual point of view, several other elements could be added. Other determining and much more relevant elements could be, for example, the proximity of water basins and dams: along the Basilicata–Apulia border, there are a series of drainage basins and dams used by a significant part of the population of Basilicata and Apulia. The contamination of these basins and/or their sources could have catastrophic effects far more serious than any benefit. The development of the study will therefore focus on three fundamental elements: multidisciplinary analysis, multi-criteria analysis and prioritization.

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