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Evaluation of Ecosystem Services in Mining Basins: An Application in the Piedmont Region (Italy)

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Abstract: Mining activities impact on the territorial system in various ways, affecting its environmental and socio-economic components. Specific evaluation tools can support decision-making processes in the context of the sustainable planning and management of mining activities. Within the evaluation procedures of mining activities, a growing interest in the analysis of Ecosystem Services (ES) is emerging. ES refer to the benefits that the natural system delivers to society, linking the health of ecosystems and human well-being. Starting from a real-world case related to the adoption of the Regional Plan of Mining Activities (PRAE) of the Piedmont region (Northern Italy), the paper aims to explore the ES valuation by considering three different mining quarries. The state of the art of the basins is compared with alternative planning scenarios from the point of view of the ES produced. The valuation is developed through GIS and the Simulsoil software, detecting the biophysical benefits produced and estimating their economic performance. The simulation results can be used to support the formulation of planning strategies, estimating the trade-offs in terms of competitive land-use values. The study also demonstrates that the integration of ES into Strategic Environmental Assessment (SEA) can produce a comprehensive impact assessment of a mining project, guaranteeing the protection and valorisation of the environmental system.

Keywords: Strategic Environmental Assessment; mining; sustainable development; circular economy; co-benefits estimation; ecosystem services

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1. Introduction

The current century is defined as the Anthropocene era [1]. Human actions and the consumption of non-renewable resources generate pressure on the environment, impacting on its high vulnerability and fragility [2]. Despite their fundamental role in economic development, mining activities represent one of the main sources of human impact on the environment and ecosystem components, both during their life cycle and after their closure. The most common examples of mining impact are soil erosion, water pollution, noise and vibrations, acid drainage, the loss of soil ecosystem services, the negative effect on landscape value, and the shrinking of scarce resources [3–6]. Therefore, the sustainable development of mining is one of the main challenges of the present day, in order to find an equilibrium between the economic, social, and environmental dimensions. In fact, this equilibrium has a particular significance in the context of mining activities, as it directly addresses both the way of acquiring natural resources and their processing. The concept of sustainable development was first used in the 1990s in the context of mining planning and management [7]. A great deal of effort has been made over the last two decades to develop a sustainable approach to mining activities [8]. In this context, the latest report SNPA [9] illustrates both the current general trends and possible future scenarios in terms of limiting impact on the environment, according to Sustainable Development Goals (SDG) targets [10]. Moreover, the emerging approach of the model of the Circular Economy, which is based on

the transformation of the relations between economy and environment [11], is also having a significant impact on the mining industry. In fact, the concept of "Circular Mining" has only recently been introduced [12] in order to apply the circular economy paradigm to the mining industry. The aim is to promote a new idea of the mining industry, grounded on the pillars of the technically feasible, economically profitable, and environmentally sustainable. However, the main efforts have been made in the legislation field, attempting to regulate the mining industries and their activities in a more transparent way [2]. In the European context, the common evaluation approach adopted is the Environmental Impact Assessment (EIA), in order to assess the environmental impact derived from mining operations [13]. In Italy, the legislative power on mining activities was transferred to the regions after the Constitutional Law no. 3/2001 [14]. Specifically, the Piedmont region has recently adopted the Regional Law of Piedmont no. 23/2016 "Disciplina delle attività estrattive: disposizioni in materia di cave" [15], which introduces the Regional Plan of Mining Activities (Piano Regionale delle Attività Estrattive—PRAE) to regulate both the planning and the management of mining activities, following the paradigms of sustainable development and circular economy.

In this scenario, this paper aims to address the importance of evaluating the impact that mining activities can have on Ecosystem Services (ES) within their life cycle, potential expansion and after their closure [16–18]. Thus, this work proposes both a literature review to illustrate the general trend in ES valuation in the mining field, and the application of ES valuation to assess the potential environmental impact produced by the possible expansion of three mining sites, located in the province of Turin, Piedmont (Italy). In detail, SimulSoil software is used for the valuation of ES both in biophysical/ecological and economic terms. Simulsoil was chosen both for the high quality of the data for the Piedmont region and its easy-to-use approach. The latter benefit is fundamental, as the application can provide the public administration with an easy process to follow for conducting quick but precise analysis for the ongoing PRAE. This application demonstrates the suitability of the Ecosystem Services Approach (ESA) for assessing the cumulative impact of mining activities [19].

The paper is organised into the following sections: Section 2 comprises the literature review about the state of the art of the application of ES in mining activities; Section 3 illustrates the Materials and Methods, focusing on the description of the case study, the application of the SimulSoil software, and the results obtained; Section 4 discusses the results, and Section 5 is dedicated to the general conclusion, with specific remarks on the possible development of the research.

2. Literature Review of the Ecosystem Services in Mining Activities

As mentioned before, the attention allocated to planning and managing mining activities within the paradigm of sustainable development and circular economy has increased in the last two decades.

Different methods and tools have been applied in evaluating the impact by mining activities on economic, social, and environmental dimensions. Lechner and colleagues collect some of the most relevant examples in the literature [20], highlighting their different fields of application and valuation objectives. One of the main promising methods concerns the ESA, due to its ability in the valuation of the cumulative impact of mining activities [21]. In detail, the application of the ESA in the field of mining planning and management can be considered innovative. This section aims to illustrate some of the more recent and relevant case studies (Table 1). The objective is to underline the current tendency of this research field and open new perspectives for future applications.

Table 1. Case studies of Ecosystem Services in the context of mining.

Authors	Case Study	Issue	ES Typology	Valuation Objective	Description	Final Outputs	Tools and Methods
Olsen et al., 2011 [22]	Rio Tinto miles Ilmenite, southeast of Madagascar	Environment; Economy; Social.	Biodiversity Hydrological Services; Carbon storage and sequestration; Bioprospecting Ecotourism.	Quantifying and evaluating the change in ES resulting from intervention of forester conservation.	The focus has been on forest biodiversity and the economic benefit associated with carbon sequestration and the hydrogeological functions of forested watersheds.	Scheme of the distribution of the cost and benefits of the conservative interventions of forests.	Benefit transfer to estimate the economic value of the considered ES.
Li et al., 2011 [23]	Mentougou district of Beijing, China	Environment	Loss due to the coal solid wastes; Loss of water self-restraint value; Loss due to the coal mining sinks; Reclamation of the abandoned lands; Loss of the soil and water.	Evaluating the mined coal value and its loss of ES in economic terms.	This evaluation puts into relation the economic value of the mined coal with the ES losses.	Economic values of different ES losses.	Market Value Method to calculate the economic value of coal mining. Market Value Method and Opportunity-Cost Method for ES losses.
Larondelle, N. et al., 2012 [24]	The largest opencast lignite mining areas in Europe is located in the south of Leipzig (Germany)	Environment	Landscape; Food and fibre production; Water resources: freshwater provision; Climate regulation; Flood regulation; Primary production; Recreation; Biodiversity.	Scenario analysis of ES.	Map regional ES and identify future development, based on current planning documents.	Maps of ES provision for a range of ES for three different scenarios. Final spidergram to illustrate the providing of ES of the three different scenarios.	ArcGis
Sanchez and Rosa, 2013 [13]	Minas Gerais State, Belo Horizonte Brazil	Environment; Social.	Crops; Livestock; Aquaculture; Wild food; Timer production; Air quality; Erosion control; Pollination; Habitat; Ethical and spiritual values; Educational and inspirational values.	Enquiring the challenges of incorporating an ecosystem services approach (ESA) to environmental impact assessment (EIA).	The study compares the approach of traditional EIA to ESA.	Matrix to correlate the impact described in EIS with the ES.	Matrix impact

Table 1. *Cont.*

Authors	Case Study	Issue	ES Typology	Valuation Objective	Description	Final Outputs	Tools and Methods
King H., 2013 [25]	Ripon city quarry, Yorkshire, England	Environment	Crop production; Flood control; Carbon sequestration; Biodiversity; Recreation; Life stock.	Assessing the types and scale of economic benefits associated with a proposed wetland restoration. Assessing the value of these services to the local community.	It is necessary to underline that the proposed post-extraction restoration will concern biodiversity and recreation.	Sum of the benefits of the different ES to the local community.	The value of these services to local communities was calculated using a benefit transfer approach which made use of Willingness to Pay (WTP).
Wang et al., 2017 [26]	Mining site in Liaoning Province, China	Environment	Product supply Water conservation Soil protection Carbon sequestration Oxygen release Air purification	Assessing the land suitability for three reclamation alternatives and identify sustainable land uses for each location.	A large mining site can be reclaimed to different land uses, providing a practical framework for integrating ES into mine reclamation.	Mapping the land suitability of forest, agricultural land and developed land. Mapping suitable post-mining land-use types. Evaluation of the ES in monetary terms.	ArcGIS; Total economic value of ES (TEV).
Qian et al., 2018 [27]	Qinghai-Tibet Plateau in the Southern Slope of Qilian Mountain, China	Environment	Food production; Raw material; Water supply; Gas regulation; Climate regulation; Environment cleaning; Water regulation; Soil formation and retention; Nutrient circulation; Biodiversity protection; Recreation and culture.	Estimate the surrounding ecosystem services value (ESV) changes by considering spatial adjacency effects. Monitor the changes in mining extent and the surrounding land cover from 1975 to 2016.	Compare the mining benefit and ESV loss associated with the development of mining areas with trade-offs.	Quantification of mining area changes in the six regions from 1975 to 2016. Mapping and spatial visualization of different land use and mining areas from 1975 to 2016.	Total Economic value (TEV); Trade-off analysis.
Wang et al., 2018 [28]	Australian mining region. Isaac River and Mackenzie River drainage sub-catchments are located in Queensland, Australia.	Environment; Society; Economy.	Biodiversity; Water quality; Erosion; Sediment transition; Sediment retention.	Quantify regional-scale cumulative impact of mining on sediment retention ES.	Sediment delivery ratio model of integrated valuation of ES. Trade-offs to calculate and map the sediment retention. The associated land-use change has significantly affected the regional ecosystem and biodiversity.	Two impact indices to quantify the cumulative impact. Sediment retention index. Mapping of sediment retention and sediment export.	ArcGis and SDR model of the InVEST software

Table 1. *Cont.*

Authors	Case Study	Issue	ES Typology	Valuation Objective	Description	Final Outputs	Tools and Methods
Demirbugan, A., 2019 [29]	Soma lignite Region, in Turkey	Environment; Society.	Timber value; Carbon sequestration; Soil erosion control; Watershed protection.	The net benefits of ES and change profile emerged in the historical process is examined in the Soma coal region located in the western part of Turkey.	Analysis of different effects of ES in different time frames and on different ES. This study also focuses the attention on the social benefits determined by the ecosystem change.	Mapping of the different mining activities in different years. Changes in economic terms of the different plantation rate.	Landsat; Total Economic value (TEV).
Wang et al., 2020 [30]	Curragh mine which is one of the largest open-cut coal mine in Australia (Figure 1). It is located in the Bowen Basin which is the largest coal basin in Australia and a catchment adjacent to the Great Barrier Reef World Heritage Marine Park	Environment	Carbon sequestration; Air quality regulation; Soil conservation; Water yield.	Assessing the cumulative impact of mining disturbance and rehabilitation on ES through mapping and quantifying changes at multiple spatial and temporal scales.	It also assesses and evaluates the synergies and the trade-offs of the considered ES with Spearman's correlation coefficient for different classes and scale.	Landscape changes from disturbance and rehabilitation were mapped using LandTrendr and the spatial patterns of those changes.	LandTrendr algorithm to detect the disturbance and the recovery in the mining with Landsat
Li et al., 2021 [31]	Yanzhou coalfield, located in Jining city, Shandong Province, China	Environment; Cultural.	Food production; Raw material production; Gas regulation; Climate regulation; Hydrogeological regulation; Waste disposal; Maintaining soil; Biodiversity; Landscape.	Identifying the ecological cumulative effect in a mining area and its spatial distribution, heterogeneity, and dynamic process.	It could display the spatial and temporal changes of ESV.	Mapping the spatial distribution of the ESV at four different timings.	Pixel-bases time series model of ecosystem services value (ESV).

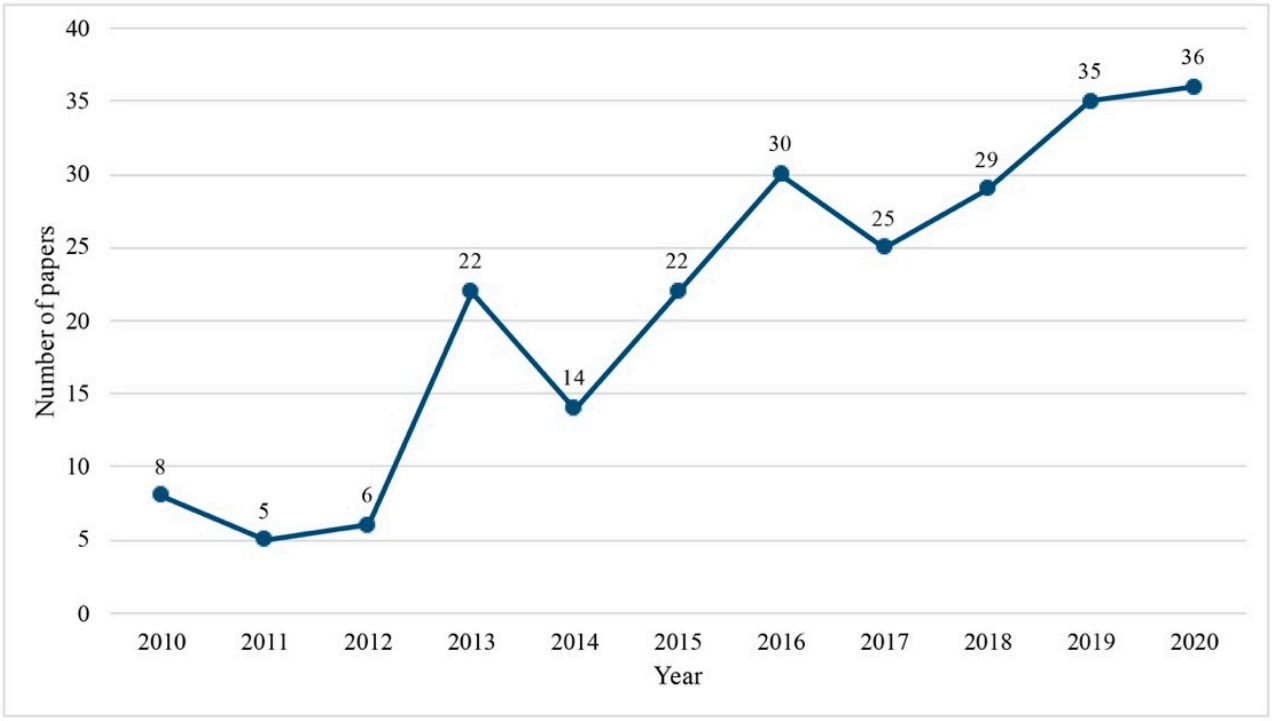


Figure 1. Trend in paper production about "mining activities" and "ecosystem services". (Elaboration of Scopus data).

For this purpose, a detailed literature review has been performed on Scopus and Google scholar platforms, with the keywords "mining activities" and "ecosystem services". The first outcome is that this research field starts to be significant in paper production since 2013. The highest number of papers in this field has been recognized in 2020, highlighting the improving interest. Figure 1 illustrates the growth in paper production of the last decade.

Table 1 illustrates and compares the selected case studies of all around the world, according to the criteria of (1) location, (2) issue, (3) ES typology, (4) valuation objective, (5) description, (6) final output, and (7) methods and tools.

What emerges from the literature review is that, in the mining context, the ESA is applied in two main ways. These are:

- Supporting both the planning and management of mining sites, through the assessment of its cumulative impact on the environmental system;
- Informing about the possible impact over time of mining restoration interventions.

Therefore, it can be generally stated that the ESA is a suitable tool to be adopted in the ex-ante phase of environmental assessment procedures, thus supporting the decision process in the mining context with a sustainable development and circular economy perspective.

Moreover, other significant tendencies can be underlined. Firstly, the general interest is to measure ES in economic terms. For this purpose, the main methodologies are the (1) Benefit Transfer [22,25], (2) Market Value Method [23], (3) Willingness To Pay (WTP) [25], and (4) the Total Economic Value (TEV) [26,27,29]. Secondly, ES mapping becomes prevalent in recent years (from 2013). Thirdly, great attention is given to the biophysical value of ES. However, few studies integrate the Economic [22,28], Social [13,22,28,29], and Cultural values [31].

In addition, it can be underlined that there is a general lack in the application of the ESA in the European context. This condition may be due to the EU legislation, which only foresees the redaction of the EIA within mining planning and management. In this context,

promising work is that proposed by Sanchez and colleague [13], where EIA evaluation is integrated with the ES measurement.

Moreover, the lack of ESA application in the EU context can be also argued by the scale of analysis. In fact, all of these selected studies analyse the ES within a regional perspective, or they are referred to a very extended mining area, as in the study proposed by Larondelle [24] which refers to the biggest mining basin in Europe.

3. Materials and Methods

3.1. Valuing Ecosystem Services in the Mining Context

The valuation of ecosystems within their services has been widely debated over time, spanning from Westman (1977) to Costanza et al. (1997), from Baveye et al. (2013) to the present day [32]. Over the last years, many different values have been proposed for capturing and measuring ES: ecological and biophysical values, economic and insurance values, as well as social and cultural values in the more recent research works. The pluralism of values provided by ES on territories has assumed even more importance, as augmented both by the number of publications on this topic and by the plurality of initiatives and research such as the Millennium Ecosystem Assessment (MA) in 2005 [33] and The Economics of Ecosystems and Biodiversity (TEEB) in 2010 [34], as well as the URBES project (Urban Biodiversity and Ecosystem Services) [35] developed from 2012 to 2015 and the CICES (Common International Classification of Ecosystem Services) [36] in 2009. All these contributions have informed the debate on the topic of ES not only at the academic level, but in particular at the political one [37].

Consequently, the valuation of ES has assumed a strategic role in a variety of planning practices [38], such as EIA and Strategic Environmental Assessment (SEA) [39,40], land-use planning [41,42], management of protected areas [43,44], and environmental damages assessment [45,46].

Moreover, in the mining context, the valuation of ES is of pivotal importance for two reasons. Firstly, it is necessary to justify the overall impact of a mining project, including the social and environmental components [21]. Secondly, mining disturbance and rehabilitation can impact directly on land use and land cover change, affecting the provision of ES [16]. These effects should be quantified and assessed to support Decision Makers (DM) both in mining development and rehabilitation practices [30].

The ES assessment supported by spatial mapping has received increasing attention [47] as it enables the identification and quantification of their spatial distributions and effects in different territories [48]. The mapping approach has a key role in supporting planning practices and decision-making processes. In fact, the spatially explicit information of mapping facilitates both the comprehension of phenomena and the interaction among the different views of the key stakeholders involved in the process [49]. Consequently, a growing number of reviews and case study applications have been developed from different perspectives and scales, as well as integrated tools for the valuation of different values of ES. The improvement of GIS technologies and the increasing availability of data has facilitated the implementation of tools such as InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) [50] and ARIES (Artificial Intelligence for Ecosystem Services) [51] at the international level, as well as, at the national level, such as LIFE+ Making Good Natura [52] and Simulsoil [53]. However, little research was carried out to assess the impact of mining activities on ES [24,47,54].

The present paper proposes a mapping analysis of losses and gains of eight ecosystems services caused by the expansion of three quarries in the Metropolitan City of Turin characterized by different types of extracted materials. In particular, this research employs the Simulsoil software to measure the ES losses and gains of different simulated scenarios of land-use changes in a selected territory. Simulsoil was chosen both for the high-quality level of the data for the case studies under investigation and for the friendly use of the software. The latter is fundamental to give to the public administration a process to be followed for conducting a similar analysis. In particular, Simulsoil allows users to

simultaneously evaluate the contribution of the following eight ES in biophysical and economic terms: Carbon Sequestration (CS), Crop Pollination (CPO), Habitat Quality (HQ), Nutrient Retention (NR), Sediment Retention (SDR), Water Yield (WY), Crop Production (CP), and Timber Production (TP).

CS is a regulating service, related to the ability of the soil to store CO_2 and avoid its dispersion in the atmosphere. The different characteristics of soils have a direct impact on the amount of CO_2 sequestered [55]. In Simulsoil, the biophysical quantification of this ES is based on the InVEST "Carbon Storage and Sequestration" model (ton/pixel). Based on the amount of ton sequestered, the tool provides supporting evidence on how 100 EUR/ton of CO_2 sequestered is calculated [56].

CPO is a regulating and provisioning ES, fundamental for the productivity of many crops that depend on pollination processes. Anthropogenic phenomena (e.g., urban sprawl, infrastructure, or use of insecticides) can strongly affect the health of pollinator species [55]. For the calculation of the contribution of wild pollinators to agricultural production, Simulsoil uses the "InVEST model Pollinator Abundance". The CPO indicator spatializes the number of pollinating species in those agricultural areas subject to the pollination service (No. of bees/pixel). The economic evaluation (226 EUR/ha) is related to the degree of dependence of crops on pollination: the percentage factor of the vulnerability of the total value of the crops is evaluated concerning the benefits due to pollination and multiplied by the presence of bees by single habitat [56].

HQ is considered as a proxy of biodiversity as the land-use changes can cause serious damages to biodiversity. This ES estimates the extent of habitat and vegetation types across a landscape and its degradation [55]. The estimation of HQ is based on the same ES model of InVEST where values range from 0 to 1 based on the context of analysis. For the economic valuation, the model used a contingence valuation that estimates the WTP of individuals for the management of natural and semi-natural green areas with high environmental value (for urban greenery 1.70–3.87 EUR/m^2; for agricultural area 0.30–0.39 EUR/m^2; for natural or semi-natural green areas 1.63–24.15 EUR/m^2) [56].

NR is a provisional ES that contributes to filtering and decomposing organic wastewater from internal waters and coastal and marine ecosystems [55]. Simulsoil uses the "InVEST NR model", which spatialized the presence of nutrients per pixel. A higher value of nutrients means lower ecosystem service provision. For the economic estimation, the biophysical value is associated with the avoided cost for an equivalent artificial purification (64 EUR/kg for a wooden buffer) [56].

SDR is a regulating ES, that considers the amount of soil removal (the richest of organic substances) due to the action of the water surface runoff and rainfall [55]. Simulsoil applies the "InVEST SDR model" and uses information relating to geomorphology, climate, vegetation, and management practices and estimates the annual soil loss starting from the RUSLE (Revised Universal Soil Loss Equation) mathematical equation. For the economic estimation, the biophysical values of potential soil erosion (ton/pixel) is associated with the avoided cost for realizing an equivalent artificial solution (150 EUR/ton) [56].

WY is a regulation ES that represents the ability of soil to filter water. This capacity of retaining water is related to land use and its characteristics (permeability, depth, texture, and absorption) [55]. For the economic estimation, the value of the service is equivalent to the avoided cost due to flood phenomena (64 EUR/m^2) [56].

CP is an essential provisioning ES for human survival as it produces food. It can increase the infiltration of nutrients such as nitrogen and phosphorus [55]. CP service is cancelled by soil consumption for construction purposes, both in the short and medium-long term. Simulsoil uses an evaluation method that is based on the spatialization of average agricultural values proposed by the Italian taxation agency, according to the classification field and the geographical area. The indicator obtained is both biophysical and economic, which expresses the actual productivity service with a parametric value of EUR/ha [56].

TP is a provisioning ES, related to the management of wood production and its collection. It also indirectly influences the maintenance of other ES (e.g., HQ). The methodology is the same as for the assessment of agricultural production, where the indicator obtained is both biophysical and economic (EUR/ha) [56].

3.2. Study Area

The Regional Law no.23/2016 introduced the PRAE to regulate the discipline on mining activities in the Piedmont region (Italy) and takes into account the basin planning and the Hydrogeological Plan (PAI) directives of Po River according to the Legislative Decree no. 152/2006 [53].

The purpose of the Regional Law is to provide a regional framework that must be incorporated by subordinated government levels, e.g., for the issuance of quarry permissions. The Regional law structures the PRAE according to three mining compartments (here and after sectors): (a) aggregates for construction and infrastructures are common mineral resources and their value is enhanced after processing and enrichment processes (e.g., gravel, sand, or concrete); (b) industrial materials are included in a broad category of minerals employed for various industrial purposes (e.g., gypsum or bricks); (c) ornamental stones are valuable natural resources that are usually employed to realize and/or recover the historical-artistic architectural heritage (e.g., gneiss or quartzites). The principles of protection of natural resources and enhancement of minerals production, in coherence with the system of government, and its territorial, landscaping, environmental, and agricultural components inspire the conceiving, planning, and management of mining activities [15].

In the context of the SEA scoping phase of the PRAE Plan, three potential planning scenarios have been identified [2]: (i) the first scenario does not provide any Regional Plan on mining activities and limits to incorporate the new provisions within the regulation in force; (ii) the second scenario focuses particularly on the environmental and landscape preservation, thus limiting the release of new mining authorizations and looking for the exhaustion of the existing quarries; and (iii) the third scenario envisages the achievement of all the objectives of the Regional Law, with particular attention on the preservation and enhancement of territorial values, mining activities, and reference market.

At the end of 2018, the Piedmont region listed 86 active quarries and mines in the metropolitan city of Turin (https://www.regione.piemonte.it/web/temi/sviluppo/attivita-estrattive/aggiornamento-elenchi-cave-miniere, accessed on 1 March 2021). About 66% of these quarries produce aggregates, 30% ornamental stones, and only 4% industrial minerals. The groups follow the three mining compartments, as established by the Regional Law (for more please see the Piedmont region—PRAE website https://www.regione.piemonte.it/web/temi/sviluppo/attivita-estrattive/piano-regionale-delle-attivita-estrattive-prae, accessed on 1 March 2021). The metropolitan city of Turin is in fact the leading area of the Piedmont region and the largest metropolitan city in Italy with a surface of 6827 km^2. Figure 2 shows the location of the active quarries in the metropolitan city of Turin, as well as the geographical position of this area at regional, national, and European scales. With the province of Cuneo, it has almost half of the active pits of the entire Piedmont region. In these two areas, the aggregates pits are the most numerous [8]. Figure 3 shows the number of active quarries of the metropolitan city of Turin sorted by the mined material and the related compartment.

Following the aim of the present research (i.e., the quantification of ES loss due to the quarries expansion for the different typologies of materials extracted), we selected three quarries in the metropolitan city of Turin, one for each mining compartment. Moreover, further motivations were considered for the selection of the three quarries among the different alternatives. Firstly, the possibility of expansion without compromising the territorial system was taken into account, such as the natural course of rivers or the presence of roads. Secondly, the dimension of the quarries was accounted for. For the ornamental group, we selected the one with the widest surface of 7307 m^2. This choice was taken to avoid a wide difference between the aggregate and industrial pits. For the latter

two, quarries were chosen similar in dimension. Table 2 reports the main data of the three quarries selected for the analysis.

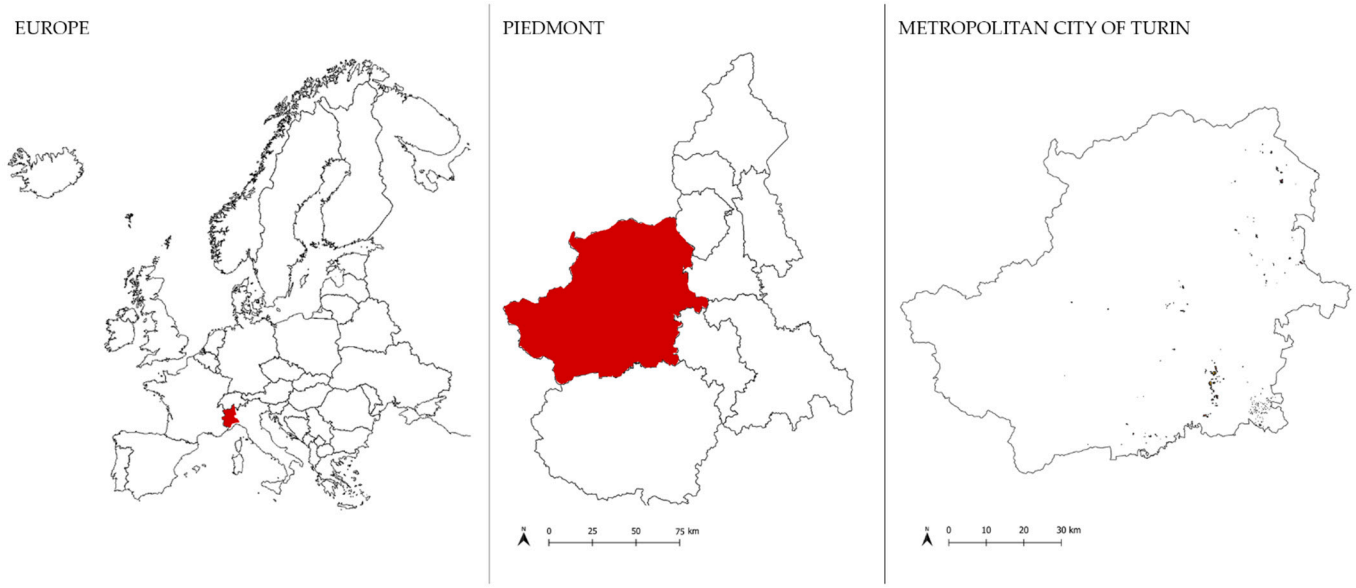


Figure 2. Localization of the Piedmont region in Europe and the metropolitan city of Turin and its quarries.

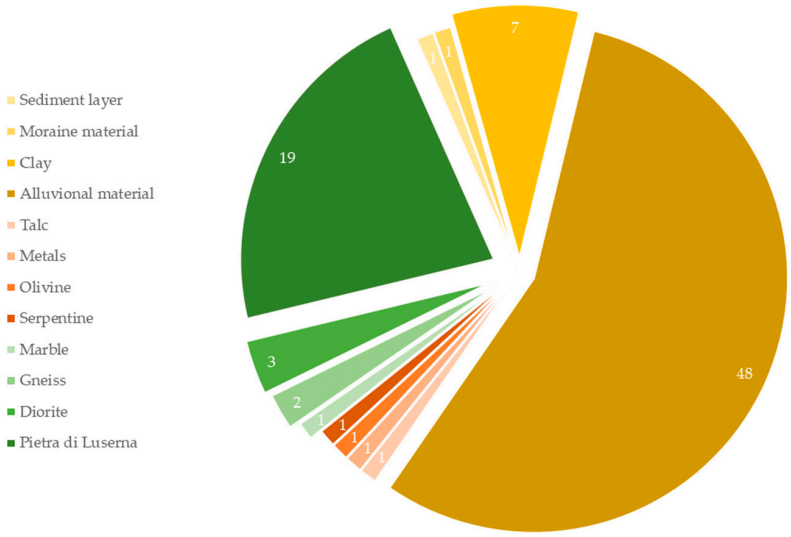


Figure 3. The number of active quarries in the metropolitan city of Turin by the extracted material. The yellow colours represent the aggregates, the greens the ornamental stones, and the reds the industrial minerals.

Table 2. Key data of the quarries selected for the analysis.

Municipality	Lithotype	Group	Expansion	Surface
Rivalta di Torino	alluvial material	aggregate	yes	30,363 m^2
Vico Canavese	diorite	ornamental	yes	7307 m^2
Vidracco	olivine	industrial	yes	35,071 m^2

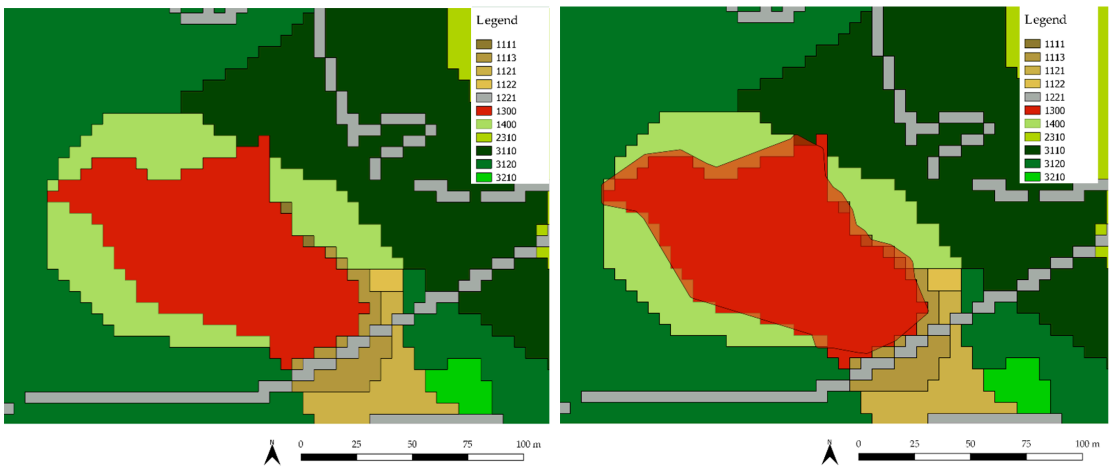
3.3. Spatial Database Assembly and ES Analysis

Three planning scenarios have been developed for each group of quarries defined based on the material extracted to explore the loss of ES due to the expansion of different

mining areas. In each scenario, various land use and land cover changes caused by the growth in the surface of the existing quarries have been simulated. In the first scenario, each quarry increases its surface by 10%. The second scenario considers an extension of the quarries equal to 20% of the existing surface. The third scenario provides for an increment of 50% of the surface.

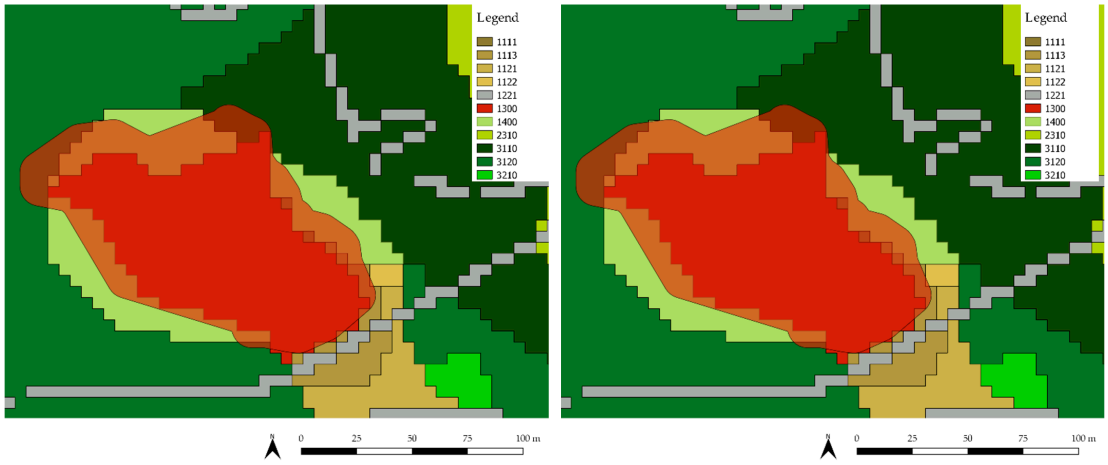
For each quarry, the three scenarios were created starting from some public access databases, in particular the cartographical data contained in the "Banca Dati Territoriale di Riferimento degli Enti (BDTRE)" available on the geocatalog by Geoportale Piemonte (https://www.geoportale.piemonte.it/cms/(Last access 1 March 2021)). The BDTRE, updated to 31 January 2018, gives a set of information for each municipality, including two shapefiles related to the existing mining areas, one for the quarries and the other for the artificial lakes. Once the mining activities were selected and the related BDTRE shapefiles are imported in QGIS software ver. 3.10.12, the three scenarios were created through an offset of the existing boundaries in order to satisfy the incremental surface values equal to the 10%, 20%, and 50% of the original areas. The extended areas are then classified as "1300—Undifferentiated mining areas, landfills and construction sites" following the local classification of land uses of Simulsoil based on the Piedmont Land Cover (LCP) (for more details see [56]). This classification is fundamental for the subsequent steps of the simulation when the single shapefiles are imported in Simulsoil. In fact, Simulsoil (a free downloadable plugin that works on QGIS 2.18.15) allows users to compare different scenarios of Land Use and Land Cover Classification (LULC) passing from a vector (.shp) to a raster file. In this research, the three scenarios created in QGIS 3.10.12 are compared to the state of the art of the territory (business as usual scenario—BAU), which is represented in Simulsoil by the LCP with a level of resolution of 5 m. Figure 4 shows the representation provided by Simulsoil of the three scenarios ((b), (c), and (d)) for one of the municipalities analyzed (Vico Canavese) compared to BAU scenario (a).

The results of the ES variation in the different scenarios are provided in Simulsoil, both graphically by spatial maps that represent each of the eight ES, and schematically by a comparative table that quantitatively reports the biophysical and economic values of the scenarios compared [55]. Details on the final results of the simulations are highlighted in the next section.



(**a**) (**b**)

Figure 4. *Cont.*



(**c**) (**d**)

Figure 4. Representation of the four simulated scenarios of the ornamental quarry of Vico Canavese as represented in Simulsoil: (**a**) BAU scenario; (**b**) scenario 10%; (**c**) scenario 20%; and (**d**) scenario 50%. 1111—continuous and dense urban fabric; 1113—continuous and moderately dense urban fabric; 1121—discontinuous urban fabric; 1122—discontinuous urban fabric; 1221—road networks and ancillary spaces; 1300—mining areas, landfills and undifferentiated construction sites; 1400—undifferentiated artificial non-agricultural green areas; 2310—stable meadows and pastures; 3110—forests with a prevalence of undifferentiated broad-leaved trees; 3120—forests with a prevalence of undifferentiated conifers; and 3210—high altitude grasslands and moors.

4. Results

The results obtained by the simulations performed on the three quarries are described in depth in this section. The selected quarries are compared with the BAU scenario based on the percentage of surface increase (10%, 20%, and 50% named, respectively, T_1—10%, T_2—20%, and T_3—50%), to analyse the biophysical and economic quantification of ES loss. Specifically, the three extensions are compared, respectively. with three BAU scenarios, corresponding to the three extensions at 10%, 20%, and 30% of the original area. These three simulations allow us to compare the state of the art of the area (i.e., simply the current situation and extension of the quarry and its surrounding with different land uses) to the incremental surface values of the quarries (respectively 10%, 20%, and 50% of the original areas). For example, the ornamental quarry of Vico Canavese is surrounded by different land uses (e.g., 1400—undifferentiated artificial non-agricultural green areas; 2310—stable meadows and pastures; 3110—forests with a prevalence of undifferentiated broad-leaved trees; 3120—forests with a prevalence of undifferentiated conifers; and 3210—high altitude grasslands and moors), as it is possible to see in Figure 4. The expansion of the quarry at 10%, 20%, and 50% generates a loss of ES due to the substitution of the mentioned land uses by the extended quarry. These differences are described in depth in Sections 3.1–3.3. In this way, it is possible to highlight both the differences and similarities of the ES loss considering the effects of the expansion of the mining activities in the surrounding territories. Then, the biophysical performances of the ES analysed are graphically shown in Figures 5–7. Specifically, biophysical performances of each ES are represented through a traffic light scale (from higher values in green, to lower values in red). The difference between green and red is based on the maximum and minimum values of each ES performances for all the extensions (10%, 20%, and 50%). The distance from a scale to another is equally distributed between the minimum and maximum values in five classes. As it is possible to see, only the five ES with a biophysical value higher than zero are represented in the figures (i.e., CS, HQ, SDR, WY, and TP), unlike Rivalta di Torino, where the expansion of the quarry also impacts CP.

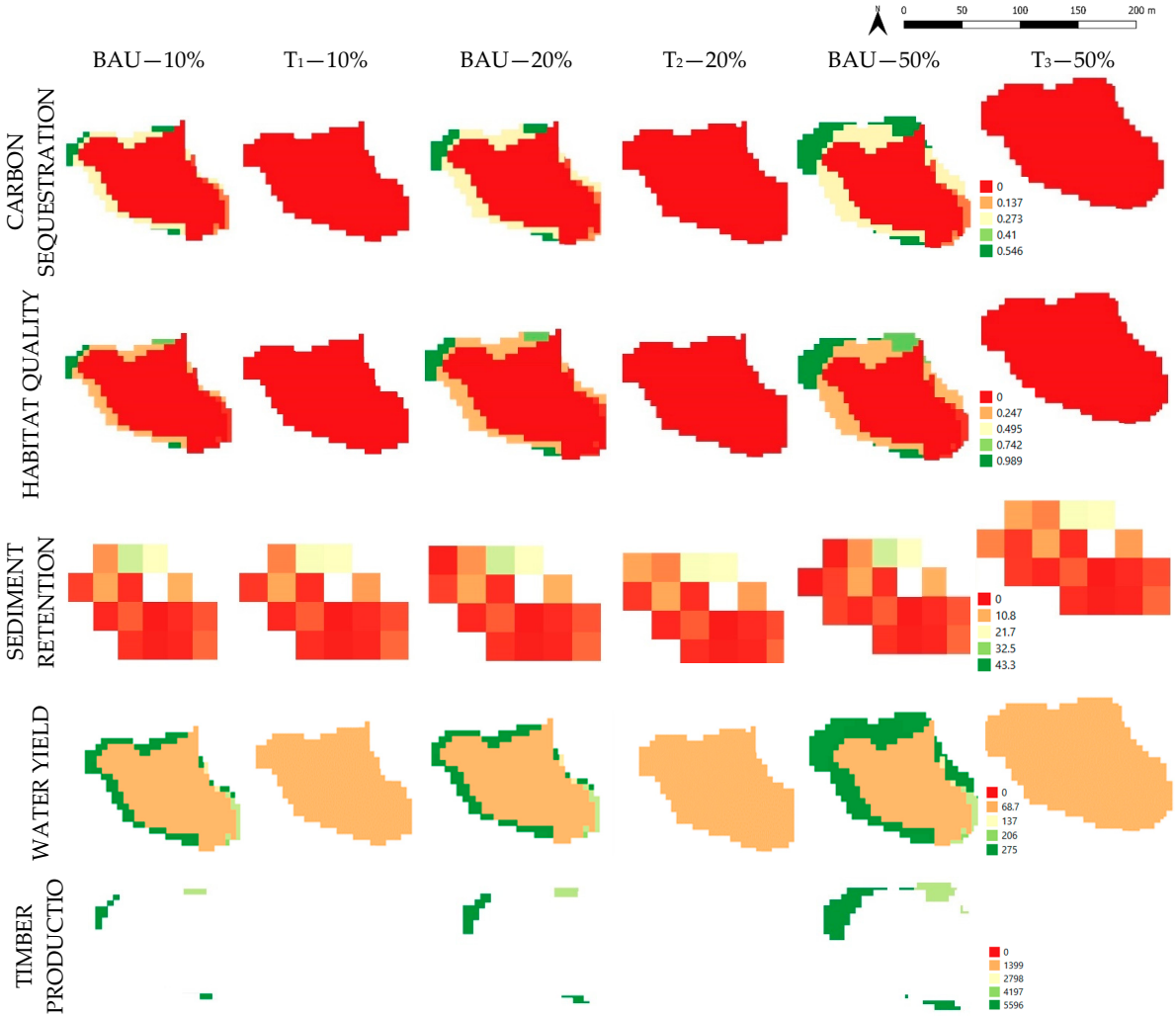


Figure 5. Representation of the biophysical performances of ES for the three planning scenarios of the ornamental quarry of Vico Canavese.

4.1. Values 10%

The expansion of the 10% of the original surface is particularly negative for the quarry located in the municipality of Vico Canavese, where the presence of wooded areas all around involves the relevant loss of CS, HQ, WY, and TP. Instead, the quarries of Rivalta di Torino and Vidracco record very similar values of these ES both before and after the simulation. For instance, they represent similar values for HQ and WY, considering the biophysical values. This is also the case for CS. However, it is possible to highlight some differences for these quarries related to TP, CPR, and SDR. The only exception is for TP. In fact, the Vidracco quarry is surrounded by woods similar to that of Vico Canavese, and the expansion of the mining activities significantly compromises this service. However, the most relevant loss for the Vidracco quarry concerns the ES of SDR. The biophysical value of this ES for the Vidracco quarry is eight times higher than for those of Vico Canavese and Rivalta di Torino, due to the number of woods and green areas around the Vidracco quarry and the lithotype characteristics of the soil. Even if the order of magnitude of the biophysical values between the BAU scenario and the 10% expansion is the same, from an economic valuation this variation has an incidence of about 10,000 EUR for the Vidracco quarry and of 2000 EUR for the quarries of Vico Canavese and Rivalta di Torino. This highlights the strong impact of this ES in the considered areas. On the contrary, looking at the economic values it is also possible to emphasize how much the loss of the WY ecosystem service is quite irrelevant between BAU and expansion scenario, as well as among the

quarries analysed. Another difference among the quarries can be stressed by looking at CP and CPO. The municipality of Rivalta di Torino is the most affected by the expansion of the mining activity concerning these ES, as it is the only area where the quarry is surrounded by agricultural fields. These effects can be detectable for the CP both in the biophysical and economic differences, instead, for CPO only in the economic columns due to the limited consequences in biophysical terms. Finally, the analysis of the economic values makes some additional considerations possible: CS, HQ, and SDR are the ES with the strongest impact on the areas considered. For the first two, the order of magnitude is of thousands, while for the third of tens and hundreds of thousands. Table 3 summarises the value of ES loss both from biophysical and economic perspectives.

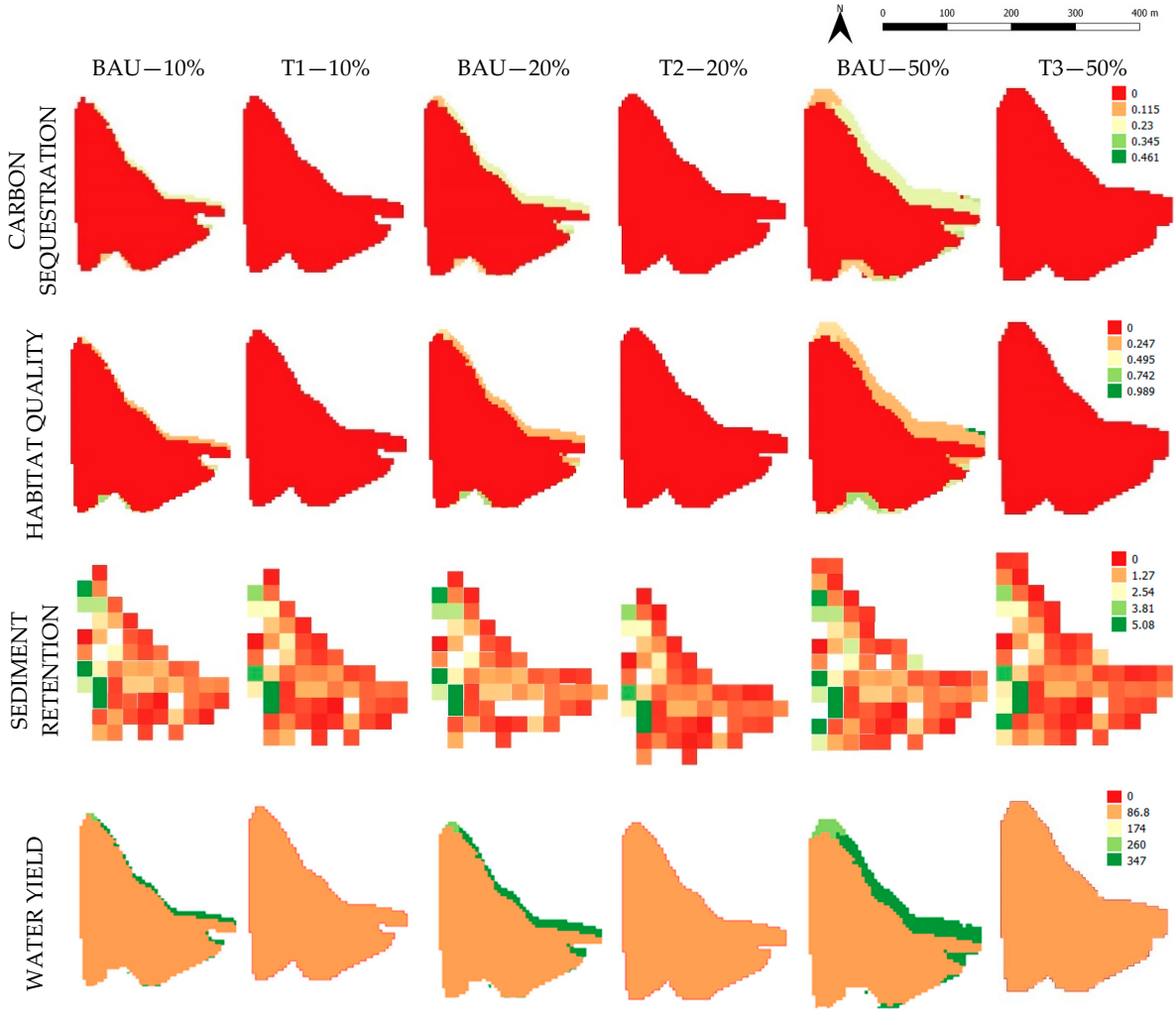


Figure 6. Representation of the biophysical performances of ES for the three planning scenarios of the aggregate quarry of Rivalta di Torino.

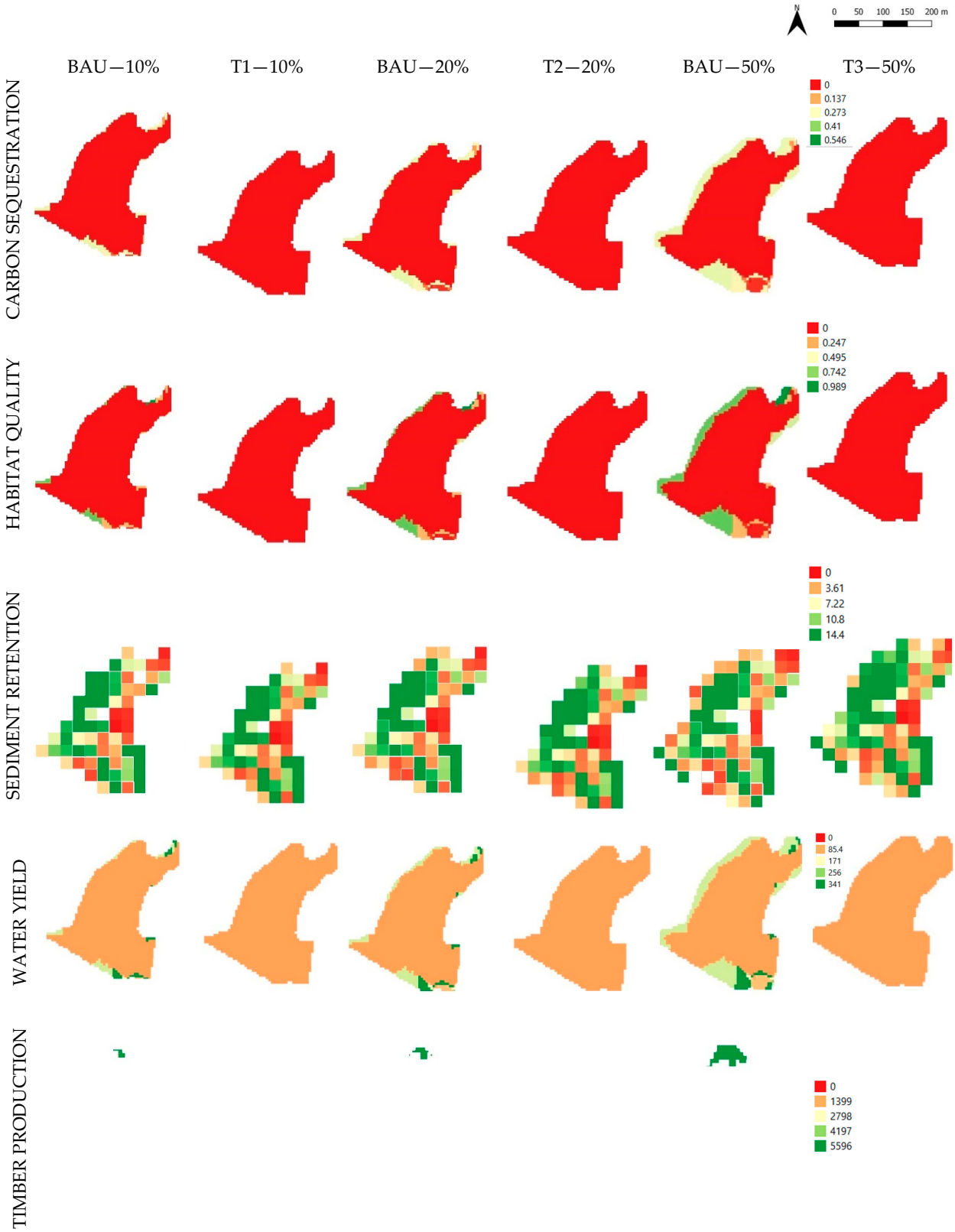


Figure 7. Representation of the biophysical performances of ES for the three planning scenarios of the industrial quarry of Vidracco.

Table 3. 10%—ES quantification for the BAU scenario and the 10% expansion of the quarry (T_1) in biophysical and economic terms for the three quarries considered.

BAU Scenario: 10% Expansion of the Quarries Surface															
ES		**Biophisical Values**						**ES**		**Economic Values**					
		Rivalta di Torino		**Vico Canavese**		**Vidracco**				**Rivalta di Torino**		**Vico Canavese**		**Vidracco**	
Code *	**u.m.**	**BAU-10%**	**T_1—10%**	**BAU-10%**	**T_1—10%**	**BAU-10%**	**T_1—10%**	**Code ***	**u.m.**	**BAU-10%**	**T_1—10%**	**BAU-10%**	**T_1—10%**	**BAU-10%**	**T_1—10%**
CS	ton	19.8	0.07	21.7	0.02	21.1	0.09	CS	EUR	1982.3	7.37	2173.2	1.83	2114.0	8.5
CPO	0-1	0.0	0.0	0.0	0.0	0.0	0.0	CPO	EUR	2.5	0.0	0.0	0.0	0.0	0.0
HQ	0-1	0.02	0.0	0.08	0.0	0.02	0.0	HQ	EUR	1208.5	0.00	1093.7	0.0	1485.5	0.0
NR	ton	0.0	0.0	0.0	0.0	0.0	0.0	NR	EUR	0.0	0.0	0.0	0.0	0.0	0.0
SDR	ton	93.9	81.1	102.8	88.2	791.1	714.1	SDR	EUR	14,089.6	12,166.4	15,411.9	13,231.4	118,668.2	107,107.2
WY	l	90.1	77.6	124.2	77.3	88.6	77.5	WY	EUR	1.1	1.0	1.6	1.0	1.1	1.0
CPR	EUR	42.6	0.0	0.0	0.0	0.0	0.0	CPR	EUR	42.6	0.0	0.0	0.0	0.0	0.0
TP	EUR	46.2	0.0	275.8	0.0	227.4	0.0	TP	EUR	46.2	0.0	275.8	0.0	227.4	0.0
Total										17,372.8	12,174.79	18,956.2	13,234.25	122,496.2	107,116.71

* CS = Carbon Sequestration; CPO = Crop Pollination; HQ = Habitat quality; NR = Nutrient Retention; SDR = Sediment Retention; WY = Water Yield; CPR = Crop Production; and TP = Timber production.

4.2. Values 20%

The expansion of 20% of the original surface of the quarries is particularly negative for the municipality of Vidracco. The presence of wooded and green areas all around involves the loss of many ES, such as CS, HQ, SDR, and TP, that are also the most relevant both in biophysical and economic terms. By contrast, the quarry located in Vico Canavese assists in a reduction in the negative impact with the quarry additional expansion. As an example, CS losses are now higher for the quarries of Vidracco and Rivalta di Torino than for the one of Vico Canavese. However, for the HQ and WY, Vico Canavese continues to lose these services proportionally to the increase in surface. As for the previous expansion at 10%, the Vidracco quarry presents again high losses for SDR. The expansion of this quarry strongly compromises the TP, as the most impacted areas are the wooden ones. The comparison among the quarries highlights that the quarry of Vidracco particularly suffers the 20% expansion, as well as the quarry of Rivalta di Torino that starts to lose much more services than before. The quarry of Vico Canavese maintains quite stable losses proportionally to the expansion. As before, it is important to highlight that Rivalta di Torino also continues to reduce its agricultural areas, thus compromising both CP and CPO values. Table 4 illustrates the ES quantification for the considered quarries, according to the BAU scenario and the expansion of 20%.

4.3. Values 50%

The expansion of 50% of the original surface of the quarries is particularly negative for the municipality of Rivalta di Torino, where the presence of some agricultural fields around the quarry involves the loss of many ES related to this sector, such as CP, CPO, and SDR. Moreover, Rivalta di Torino is also the second in terms of loss of ES for CS, HQ, and WY. Vidracco remains the most affected by the expansion for CS and TP, as its quarry is surrounded by wooden areas. Instead, HQ and WY services are, as usual, most relevant for Vico Canavese. Table 5 shows the ES quantification both in biophysical and economic terms for the three quarries analysed, according to the BAU scenario and the 50% of the expansion.

Table 4. 20%—ES quantification for the BAU scenario and the 20% expansion of the quarry in biophysical and economic terms for the three quarries considered.

BAU Scenario: 20% Expansion of the Quarries Surface															
ES		**Biophisical Values**						**ES**		**Economic Values**					
		Rivalta di Torino		**Vico Canavese**		**Vidracco**				**Rivalta di Torino**		**Vico Canavese**		**Vidracco**	
Code *	**u.m.**	**BAU-20%**	**T_2—20%**	**BAU-20%**	**T_2—20%**	**BAU-20%**	**T_2—20%**	**Code ***	**u.m.**	**BAU-20%**	**T_2—20%**	**BAU-20%**	**T_2—20%**	**BAU-20%**	**T_2—20%**
CS	ton	37.3	0.08	26.1	0.02	41.3	0.09	CS	EUR	3728.2	8.1	2608.4	1.9	4126.9	9.4
CPO	0-1	0.0	0.0	0.0	0.0	0.0	0.0	CPO	EUR	5.0	0.0	0.0	0.0	0.0	0.0
HQ	0-1	0.03	0.0	0.1	0.0	0.05	0.0	HQ	EUR	2032.2	0.0	1327.9	0.0	3336.9	0.0
NR	ton	0.0	0.0	0.0	0.0	0.0	0.0	NR	EUR	0.0	0.0	0.0	0.0	0.0	0.0
SDR	ton	99.7	79.1	103.2	98.3	874.1	828.0	SDR	EUR	14,961.4	11,859.4	15,476.1	14,745.6	131,113.9	124,197.3
WY	l	100.6	77.4	129.8	77.6	93.5	77.5	WY	EUR	1.3	1.00	1.6	1.0	1.2	1.0
CPR	EUR	87.9	0.0	0.0	0.0	0.0	0.0	CPR	EUR	87.9	0.0	0.0	0.0	0.0	0.0
TP	EUR	45.8	0.0	342.0	0.0	602.1	0.0	TP	EUR	45.8	0.0	342.0	0.0	602.1	0.0
Total										20,861.8	11,868.54	18,428.1	14,748.5	139,180.9	124,207.7

* CS = Carbon Sequestration; CPO = Crop Pollination; HQ = Habitat quality; NR = Nutrient Retention; SDR = Sediment Retention; WY = Water Yield; CPR = Crop Production; and TP = Timber production.

Table 5. 50%—ES quantification for the BAU scenario and the 50% expansion scenario in biophysical and economic terms for the three quarries considered.

BAU Scenario: 50% Expansion of the Quarries Surface															
ES		**Biophisical Values**						**ES**		**Economic Values**					
		Rivalta di Torino		**Vico Canavese**		**Vidracco**				**Rivalta di Torino**		**Vico Canavese**		**Vidracco**	
Code *	**u.m.**	**BAU-50%**	**T_3—50%**	**BAU-50%**	**T_3—50%**	**BAU-50%**	**T_3—50%**	**Code ***	**u.m.**	**BAU-50%**	**T_3—50%**	**BAU-50%**	**T_3—50%**	**BAU-50%**	**T_3—50%**
CS	ton	85.9	0.1	66.4	0.02	123.5	0.1	CS	EUR	8585.5	10.0	6638.9	2.5	12,344.9	11.7
CPO	0-1	0.0	0.0	0.0	0.00	0.0	0.0	CPO	EUR	17.8	0.0	0.0	0.0	0.0	0.0
HQ	0-1	0.1	0.0	0.2	0.00	0.1	0.0	HQ	EUR	5236.5	0.0	3560.5	0.0	11,003.1	0.0
NR	ton	0.0	0.0	0.0	0.00	0.0	0.0	NR	EUR	0.0	0.0	0.0	0.0	0.0	0.0
SDR	ton	150.1	102.0	109.8	105.9	970.9	982.1	SDR	EUR	22,515.1	15,302.2	16,469.8	15,877.4	145,635.4	147,309.9
WY	l	119.3	77.6	167.9	77.56	108.8	77.5	WY	EUR	1.5	1.0	2.1	1.0	1.4	1.0
CPR	EUR	319.8	0.0	0.0	0.0	0.0	0.0	CPR	EUR	319.8	0.0	0.0	0.0	0.0	0.0
TP	EUR	238.6	0.0	1083.3	0.0	2256.0	0.0	TP	EUR	45.8	0.0	342.0	0.0	602.1	0.0
Total										36,914.7	15,313.1	27,754.7	15,880.8	160,237.7	147,322.5

* CS = Carbon Sequestration; CPO = Crop Pollination; HQ = Habitat quality; NR = Nutrient Retention; SDR = Sediment Retention; WY = Water Yield; CPR = Crop Production; and TP = Timber production.

5. Discussion of the Results

As the three quarries have different surfaces, as well as the comparison of the outputs produced by Simulsoil, we also analysed the delta between the BAU scenario and the three simulated expansions for each quarry. Figures 8 and 9 illustrate, respectively, the ES losses in biophysical and economic perspectives, according to the expansion of 10%, 20%, and 50%.

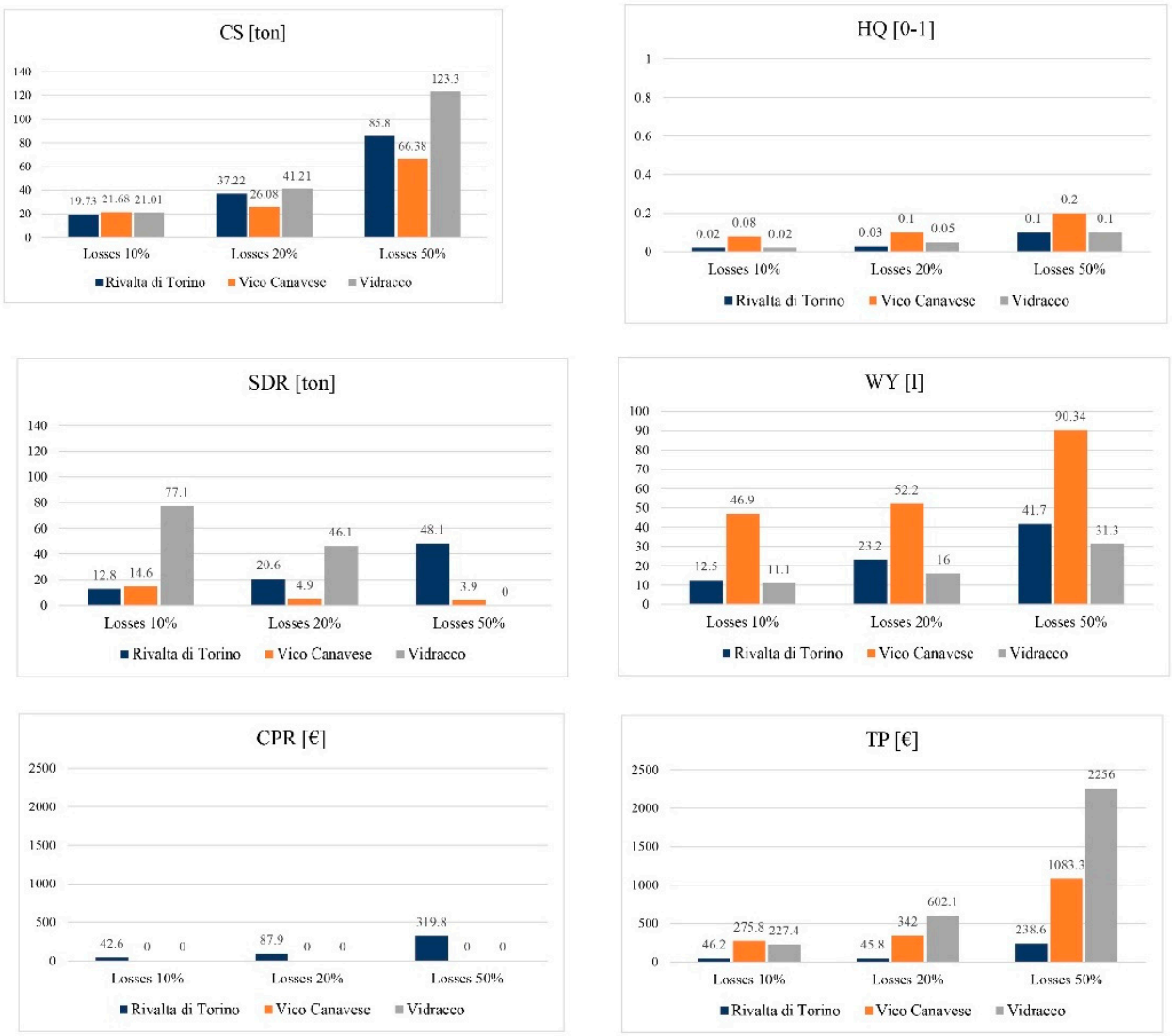


Figure 8. ES losses comparison in biophysical terms, according to the expansion of 10%, 20%, and 50%.

As can be seen in Figures 8 and 9, the 10% expansion has negative consequences, especially for Vico Canavese, both in biophysical and economic terms. This is due to the fact that the surrounding areas are characterized by woods, thus they are immediately compromised by the expansion. In fact, this necessarily affects the performance of CS, WY, and TP. Vico Canavese shows a less impact on ES losses according to its expansion at 20% and 50%, both in economic and biophysical terms. In terms of policies, this result suggests that the ornamental quarry of Vico Canavese should be expanded only if a wide development of the mining activities is planned, otherwise it will not be convenient. Conversely, the extension of the alluvial quarry of Rivalta di Torino has even more negative effects if the surface increases (i.e., the 20% extension is worse but the 50% is the worst). Based on these results, public administration should reflect on the extension of this quarry for the impact on the ES and in general on the environmental system. Similarly, in Vidracco the increase in the surface area generates the loss of many ES, as underlined by Figures 8 and 9. However, the most negative

consequences for Vidracco have been recorded as very evident for CS and TP according to the 20% and 50% expansion, whereas, for SDR, Vidracco recorded major losses at 10% expansion. However, the most negative consequences for Vidracco have been recorded as very evident at 20% expansion and they are less evident at 50%. Concerning the simulations on the quarry of Rivalta di Torino, the loss of ES is proportional to the increase in the mining area. In this sense, the quarries of Vico Canavese and Rivalta di Torino can be comparable in terms of losses at the 20% expansion.



Figure 9. ES losses comparison in economic terms, according to the expansion of 10%, 20%, and 50%.

Moreover, looking at the sums of the economic values (Figure 9), the Vidracco quarry is revealed to be the most compromised due to the expansion. However, this amount can

be misleading for two reasons: the first concerns the extension of this quarry as the largest one, consequently, the percentage growth also determines a greater expansion than the other quarries. Secondly, the Vidracco quarry shows the highest economic impact due essentially to SDR losses. On the contrary, the quarry of Rivalta di Torino might seem less affected by the extension of the mining area, if the economic values are the only ones considered. Instead, from a biophysical point of view, the expansion of this quarry has effects on several ES, especially those related to agricultural activities (CP and CPO). In this sense, DM should carefully consider the benefits and impact in the expansion of this quarry, as the effects on the agricultural sector are quite relevant. In light of the obtained results, the ESA demonstrate fruitful potentialities in the context of environmental planning and management and thus envisioning new research directions for the mine regional planning.

6. Conclusions

This study illustrates both the methodology of the ESA through a review of the literature related to the mining field and the application of ES evaluation for three different quarries in the province of Turin (Italy). Based on the results obtained in this application, it is possible to assert that the application of the ESA allowed the investigation of the potential impact that can be generated by different scenarios of expansion of the original surface of the three quarries investigated. The Simulsoil software was used for the quantification of both the biophysical and economic losses of eight ES with respect to the geographic space by the simulation of three different expansions equal to 10%, 20%, and 50% of the original surface of the quarries. The process developed in this research can be employed in the assessment and planning of new sustainable and transparent policies, as well as in the support of existing plans to examine their impact and vulnerability with respect to the environmental system [57]. The results obtained could help, for example, regional authorities, planners, technicians, environmental subjects, and other bodies to envision alternative planning scenarios for mining activities and to identify both general and site-specific strategies. A potential implementation of the ESA in the adoption of the PRAE of the Piedmont Region could support the assessment of the environmental impact that the PRAE can generate on the environmental system, thus aiding DM to define actions of mitigation and environmental compensation in relation to the future localization of new quarries or the potential expansion of the existing quarries in the Piedmontese territory. In addition, the ESA could play a very important role in both the ex-ante and ex-post phases of the evaluation process. On the one hand, the ESA can analyse the existing environmental status of the region in terms of the generation of ES where quarries are located or in their vicinity. On the other hand, the monitoring phase might also be enriched by the ESA. As the monitoring step is devoted to the measurement of the PRAE performance, the ESA can integrate this step by focusing on the changes in the biophysical and economic values. In this way, the monitoring can contribute more effectively to the success of the strategies and to orientating the direction that the PRAE will take. The ESA can operate with a multi-scalar approach, starting from the regional scale and then focusing on the individual quarry and its neighbouring areas. The proposed method is intended to emphasize the implications of integrating ES services analysis into planning for environmental management [58] and for the development of strategies that reduce the negative environmental impact of land use across multiple services [59]. Moreover, the proposed application offers two main elements of innovation. Firstly, this paper has proposed the use of a consolidated approach to the mining activities sector. Secondly, it has applied the ES evaluation at a small scale of analysis, unlike the majority of the case studies available in the literature. An additional objective concerned the analysis of both the pros and cons of the approach, with the aim of verifying its replicability and validity, guaranteeing the transparency of the participatory and planning processes.

The evaluation performed underlines how the ESA can be a technical tool capable of sensitizing both operators and companies in the transition towards more sustainable and circular mining activities. In fact, it is possible to evaluate the cumulative impact

of land use, in terms of the environmental and economic aspects, also highlighting their relationships [20]. In this context, DMs have the fundamental role of activating policies with a shared goal of environmental sustainability, where economic development and nature conservation are strictly related [57,60]. With this evaluation tool, DMs can easily identify the areas suitable for the localization of new mining sites amongst those that present raw materials potential, or the expansion of the existing sites during the life cycle of the PRAE Plan, in order to achieve the highest ecological and biophysical performance. This management perspective of planning is aligned with the achievement of global objectives of sustainable development, such as SDG, or the limits defined by the Paris Agreement of the United Nations and the Aichi Targets [57], among others. Therefore, the ESA represents a promising approach to be integrated within assessment and planning procedures, with particular regard to highly impactful anthropogenic activities such as mining. In fact, it can also be applied to support the assessment of social impact and facilitate the participatory process related to mining planning, according to the wide-ranging perspective of sustainable development, circular economy, and resilience [61]. The ESA has great potential within integrated evaluation frameworks to assess multiple impacts on the environment caused by urban and territorial transformations. For example, the integration between the ESA, System Dynamics Modelling, Multicriteria Decision Analysis, and the Driving forces, Pressure, State, Impact, and Response (DPSIR) model can effectively help DM in all the phases of the SEA evaluation process [2,37,62–64]. In this perspective, a promising development could be the integration of the ESA with the SIA, providing a multi-disciplinary understanding of social, economic, and environmental impacts, as well as their interactions and aggregations [20]. The involvement of public bodies, operators, and companies can facilitate the understanding of the real potential of the quarries considered, as well as promote sensibilization regarding both the biophysical and economic impact and losses of other mining areas in the territory. As a future perspective to carry on the discussion begun in this paper, other values could be integrated into the evaluation, spanning from labour forces to socio-cultural benefits.

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