

## Article

# Sustainable Post-Mining Land Use: Are Closed Metal Mines Abandoned or Re-Used Space?

Sonja Kivinen

Department of Geographical and Historical Studies, University of Eastern Finland, P. O. Box 111, FI-80101 Joensuu, Finland; sonja.kivinen@uef.fi; Tel.: +358-40-5884185

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**Abstract:** Sustainable land use in post-mining areas has received more attention only recently. This study examined landscape characteristics and post-mining land use in 51 metal mining sites in Finland. Studied mines were closed during the period of 1924–2016, and over half of them had been active more than 10 years. Mines were typically located in sparsely populated forest landscapes. Cultural and recreational functions were found in one third of the sites, especially in significant historical mining areas close to the population centers. Further, nearly one third of the post-mining sites included new activities related to industry and infrastructure. The diversity of post-mining functions was generally limited in small and isolated sites. Re-opening of five closed mines was planned or under development, and exploration permits (or claims) were applied or admitted for half of the post-mining areas. The results showed that every closed mine is unique and thus, sustainable post-mining land use requires careful evaluation of potentials and limitations (e.g., contamination and other hazards) of the sites. Increasing sizes of new mining projects calls for paying more attention on future post-mining landscapes in order to avoid degraded and underused areas from environmental, social and economic perspectives.

**Keywords:** extractive industries; Finland; industrial landscapes; land use; metal mines; mining legacies; post-mining

## 1. Introduction

Mining is temporary land use with a highly variable duration in different locations. A mine is closed when the resource is depleted or exhausted, or mining is no longer economically profitable due to a high cost of mining or low market prices [1–3]. Local communities in post-mining areas have traditionally faced challenges related to degraded landscapes, lowered environmental quality and socio-economic problems. Previously mines were often abandoned after the production phase without considering any potential risks to humans and the environment or social dimensions [4–7]. It has been only recently when sustainability issues related to post-mining phase have received more attention [4,8–13].

Mining has substantial impacts on local and regional environments during the production phase [14–18]. Further, abandoned or inadequately closed mines may continue to degrade surrounding land, water bodies and air [19–21]. Globally, there is a huge number of mines where acceptable mine closure did not take place or was incomplete [5,6,22–25]. Today, a majority of mining companies view closure and reclamation planning as an integral part of the operating plan [26–28]. Mine reclamation aims at returning land to a stable condition to ensure public safety, to minimize potential negative environmental impacts, and to allow alternative land use opportunities [4,29–33].

Post-mining regions include various landscape and geophysical changes, and often differ significantly from surrounding (rural) landscapes. Mining leaves behind various land disturbances, such as open pits, waste rock dumps, tailings, and roads. Further, post-mining sites can also include

standing buildings, above ground and underground structures and machinery [34–36]. There are no universal reclamation planning schemes for former mining areas, and thus, detailed objectives of closure plans and post-mining measures are largely site-specific [37–41]. In general, there will always be differences in pre-mining and post-mining ecosystems and landscapes [22,42,43].

The most common post-mining land use purposes include agriculture, forestry, recreation, construction, conservation and lakes [22,44]. Although perception of post-mining landscapes is often negative, they can harbor unique natural, cultural and economic potential [36]. Examples of these are pastures, aquaculture, wildlife habitats, educational, sport and leisure facilities and industrial uses [44–49]. Post-mining land use is generally determined by economic, social and technical factors as well as mine site properties. The suitability of former mining sites for different activities depends, for example, on current land use surrounding the site, infrastructure and facilities, and the extent of any environmental impacts, such as soil and water contamination [22,44,50–52]. Mines can also be reopened e.g., as a result of higher mineral prices or new technologies [1,3,53].

The first metal mines in Finland date back to the 16th century, and modern mining industry started to develop during the first part of the 20th century. Thus far, the most active mining period took place in 1960–1980. Since then, a large number of mines has been closed [54,55]. During the recent years, the Finnish metal mining industry and mineral exploration have experienced rapid growth [56]. In the Fraser Institute's 2016 survey for mining companies, Finland was ranked the fifth most attractive jurisdiction in the world for mining investment [57].

A national inventory of mining waste facilities which can cause serious negative environmental impacts or have the potential to become a serious threat to the environment was completed in 2012 [58]. Otherwise, post-mining landscapes are relatively poorly known despite a long mining history of Finland (but see [59]). In general, there is a limited amount of information on post-mining land use over wide geographical areas, as scientific studies have often focused on specific mining sites or regions [35,60–62]. Recent increases in mining activities in northern Europe calls for more research on mining legacies to ensure sustainable land use both in current and future post-mining areas. This paper focuses on characteristics of post-mining landscapes and land use in metal mining sites closed during the past ca. 100 years. Specifically, the aims were (1) to study general properties of closed metal mines and the surrounding landscape, (2) to analyze post-mining land use and the re-utilization of different mining site elements for new activities, and (3) to examine potential new mining activities in post-mining sites.

## 2. Materials and Methods

### 2.1. Spatial Data on Mining and Land Use

Various open-access spatial databases were utilized to study characteristics of metal mines and to analyze current land use and functions in post-mining sites. Spatial data on mines were derived from Mines product extracted from the open access Mineral Deposit database of the Geological Survey of Finland [55]. The Mines product includes active, closed and historic mines as well as mines under development and contains information on e.g., the start and end years of mining, the main commodities of the deposit, and the total ore and waste rock mined. A total of 51 mines closed during the period of 1924–2016 were selected for the study (Figure 1). One of the mines (Taivaljärvi) included an exploration tunnel only. Six closed mines with mainly experimental, small-scale production as well as historic mines operating between 16th and 19th centuries were excluded from the analyses. Spatial data on applied and admitted exploration permits and mining permits (called claim and concession under the old Mining Act, respectively) were derived from the database of the Finnish Safety and Chemicals Agency [63].

Both current and previous post-mining land use activities in each site were included in the study. The locations of cultural heritage sites of national significance and protected buildings were derived from the databases of the National Board of Antiquities [64]. Sport sites, recreational areas and

outdoor routes were mapped using the LIPAS database [65]. Scuba diving in closed mines was studied using a database of dive sites in Finland [66]. Topographic maps and aerial photographs available in a public service Citizen's MapSite by the National Land Survey of Finland [67] were utilized to study the occurrence of buildings and other infrastructure in the mining sites, to measure the area of the open-pit mines (pit lakes) and to examine potential reforestation. Additional information on post-mining land use and activities were derived from online publication databases and specific websites (e.g., communities, mining companies, local newspapers).

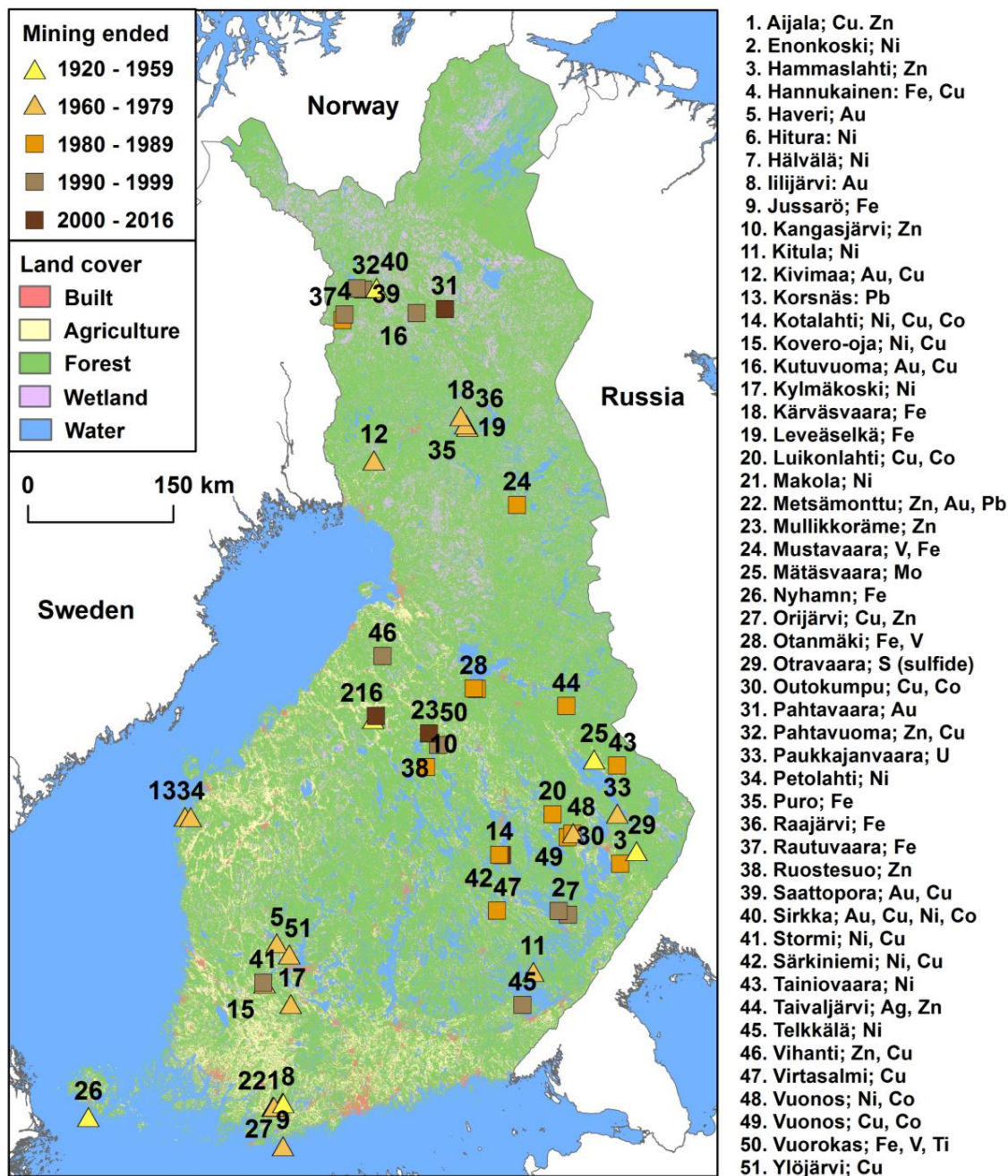


Figure 1. The locations of 51 studied post-mining sites in Finland.

Information on potential environmental accident hazards and need for further environmental risk assessment were derived from an inventory of closed and abandoned extractive waste facilities [58]. This paper does not deal with specific reclamation measures that have taken place in different sites

after the mine closure, or environmental problems in detail (see [58,59]) for more information. Instead, restrictions and hazards related to reutilization of post-mining environments are discussed at the end of the paper.

## 2.2. Landscape analyses

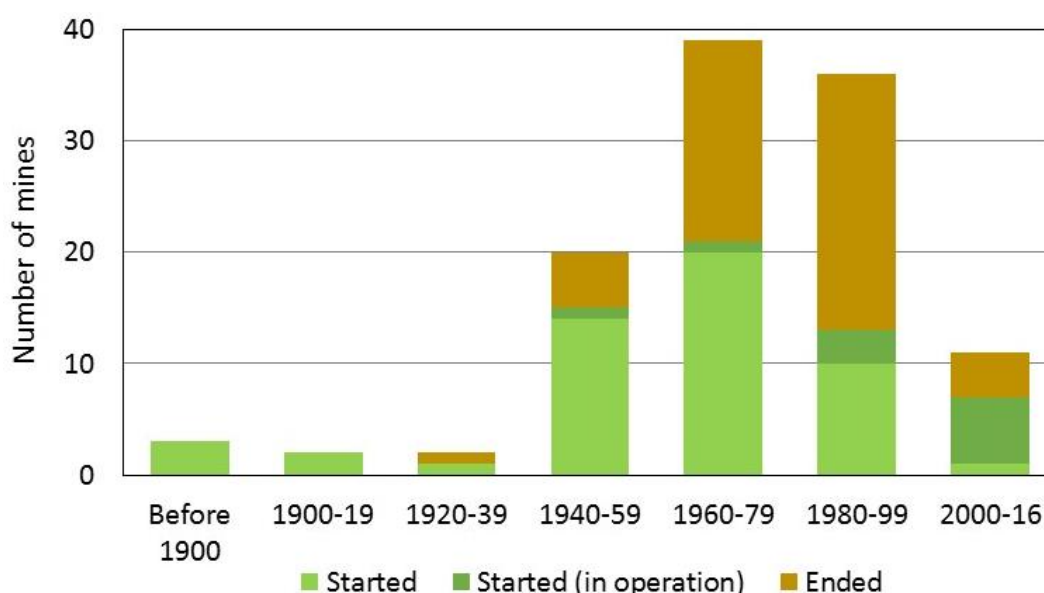
The characteristics of the surrounding landscape were studied within a 5 km buffer zone calculated around the central point of each mining site. Land cover information were derived from the CORINE Land Cover 2012 database with 25 m spatial resolution [68]. Land cover classes were reclassified as: (1) urban areas, (2) industrial areas, (3) leisure and sport areas, (4) agricultural land, (5) forest, (6) wetland, and (7) water bodies. Population density within the buffer zone was calculated using population grid data in 1 km resolution. Distance of the mining sites to the densely populated areas and the nearest villages were calculated using the Urban form data with 250 m resolution [69]. A densely populated area was defined as an area with at least 200 inhabitants, the distance between buildings being less than 200 m [70]. Village settlements describe densely built and populated areas outside urban regions with more than 39 inhabitant. All spatial analyses were carried out using ArcGIS 10.2 software (Esri).

## 3. Results

### 3.1. General Characteristics of Closed Metal Mines

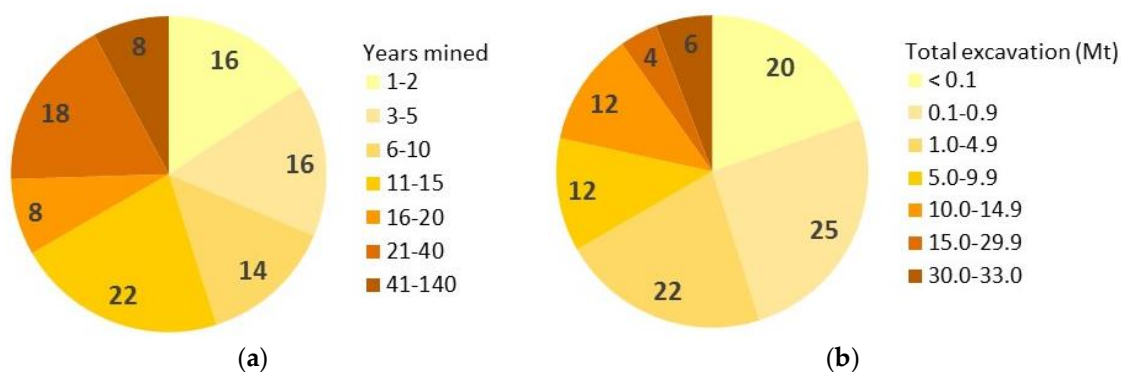
#### 3.1.1. Active Mining Period and Main Commodities

A majority of the studied metal mines were opened in 1940–1990 (Figure 2). Three of the mines closed in the 20th century had started their production already in the 18th and 19th centuries. Approximately one third of the mines were closed in 1960–1979 and half of the mines in 1980–2016. Less than half of the mines were active up to 10 years, 30 % of the mines operated 11–20 years, and 26% of the mines more than 20 years (Figure 3a). The total excavation (ore plus waste rock) was less than 1 Mt in nearly half of the mines and exceeded 10 Mt in 22% of the cases. (Figure 3b). In comparison, the total excavation so far exceeded 10 Mt in over half of the currently active metal mines ( $n = 11$ ; range 0.4–182 Mt).



**Figure 2.** The start and end years of the studied metal mines ( $n = 51$ ) and the start year of metal mines currently in operation ( $n = 11$ ).



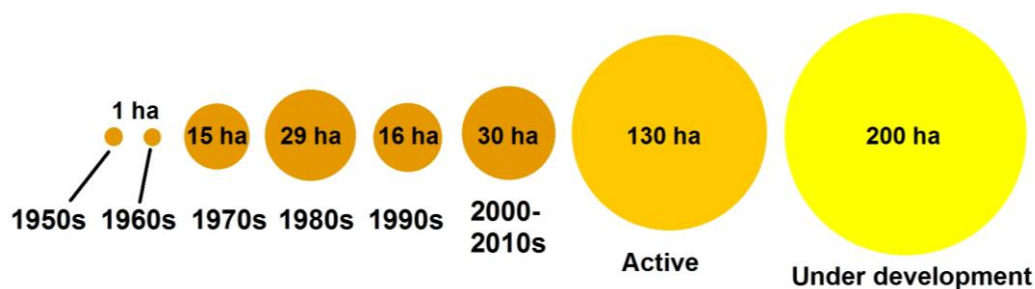


**Figure 3.** The proportion of (a) the number of active years and (b) the total excavation (ore and waste rock) in studied metal mines.

The most commonly mined metals included copper, nickel and iron (22–35% of the mines) as well as zinc and gold (16–18% of the mines) (Figure 1). Other main commodities were cobalt, molybdenum, vanadium, titanium, lead, silver and uranium.

### 3.1.2. Mining Methods, Mine-Site Elements and Environmental Risks

Over half of the sites included both underground and open-pit mining, 31% of the sites included open-pit mining only and 19% of the sites underground mining only. The size of the open-pit mines (nearly all water-filled;  $n = 43$ ) ranged from less than 0.1 ha to 30 ha, and 86% the open-pits were smaller than 5 ha [55,59,67] (Figure 4). In comparison, the sizes of the active open-pit mines or mines under development ( $n = 14$ ) ranged from 1.8 ha to 200 ha, half of them being larger than 60 ha [67,71–78]. According to the interpretation of aerial photographs and a recent study [59], approximately 50% of the closed mining sites contained buildings and other constructions. Further, 50% and 63% of the sites included tailings and waste rock piles, respectively.



**Figure 4.** The largest open-pit mine closed in different decades from the 1950s to the 2010s, and the largest active and planned/under development open-pit mines.

Approximately 70% of the closed metal mines studied here were included in a recent inventory of closed and abandoned extractive waste facilities [58]. According to the inventory results, none of them presented major accident hazards. However, nearly all of the closed mine sites would require further assessment of the current state and (further) reclamation needs of the waste facilities and their environmental impacts, such as acid mine drainage and dusting.

### 3.1.3. Landscape Properties

Approximately 75% of the post-mining landscapes were dominated by coniferous and mixed forests and, to a lesser degree, deciduous forests. Agricultural land covered approximately 8% of the post-mining landscapes. The cover of agricultural land exceeded 10% of the total area in one

third of the post-mining regions. The average cover of urban, industrial and leisure areas was small (1–2%). Wetlands and water bodies (lakes, rivers, sea) covered on average 5% and 12% of the total area, respectively.

Closed mines were mostly located in sparsely populated areas. The average population density in the post-mining landscapes was 13 people/km<sup>2</sup> (the whole country = 18 people/km<sup>2</sup>). In nearly half of the landscapes, population density was less than 5 people/km<sup>2</sup>, and only 17% of the landscapes had population density 23–77 people/km<sup>2</sup>. Approximately 25% of the studied mines were located within 500 m from the densely populated area or a village. Further, 47% of the mines were located within 500–5000 m (connected) and 27% of the mines more than 5000 m (isolated) from the nearest densely populated area or a village.

### 3.2. Post-Mining Land Use and Functions

#### 3.2.1. Culture and Recreation

Commercial and public cultural and recreational activities were found in a total of 35% of the post-mining sites (Table 1). These mines were commonly located in densely populated areas or next to the villages (Figure 5). Eight sites were classified as cultural heritage sites of national significance in the inventory by National Board of Antiquities [64,79–86]. A majority of these mines had been in operation over several decades. Museums presenting gold and copper mining history were established in two sites [87,88]. A mining themed holiday village was located in two post-mining areas and a restaurant in three sites (gold, copper, iron) [89–91]. Various cultural events were arranged in an old copper mining area and concerts in a closed open-pit molybdenum mine [88,91]. A motorsport venue had been constructed in the tailings area of an old copper mine [92]. A nature/geological trail was found in three mining areas (iron, lead), and one of these sites was located within a national park [93–95]. Other recreational activities particularly in the tailings area of closed mines (copper, iron, zinc, nickel) included e.g., bird watching [96,97], a golf and disc golf courses [88], greyhound racing [98] and a shooting range [60]. Tailings were also used for rally and dirt-bike tracks [59,99]. At least nine water-filled open pits and one mining island (copper, gold, iron, molybdenum, nickel, zinc) were popular dive sites [66] and one lake area in the vicinity of a closed mine was a swimming place [99].

**Table 1.** Current or former reutilization of former mining sites and their specific elements. Forestry use was not included in the analyses. See Figure 1 for the names and locations of mines (numbered superscripts).

Culture & Recreation	Industry & Infrastructure	Other
<i>Mining site (in general)</i>		
<ul style="list-style-type: none"> <li>• Cultural heritage site of national significance<sup>5,9,14,25,27,28,30,46</sup></li> <li>• Outdoor recreation<sup>14,28,46</sup></li> <li>• Nature trail<sup>9,13,19</sup></li> <li>• Holiday village<sup>5,36</sup></li> <li>• Museum<sup>5,30</sup></li> <li>• Dive site<sup>9</sup></li> <li>• Swimming<sup>51</sup></li> <li>• Disc golf course<sup>30</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Sand/gravel pit<sup>4,43</sup></li> <li>• Bus scrabyard<sup>2</sup></li> <li>• Concrete element factory<sup>48</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Military facilities<sup>9</sup></li> <li>• Fire rescue exercises<sup>5</sup></li> </ul>

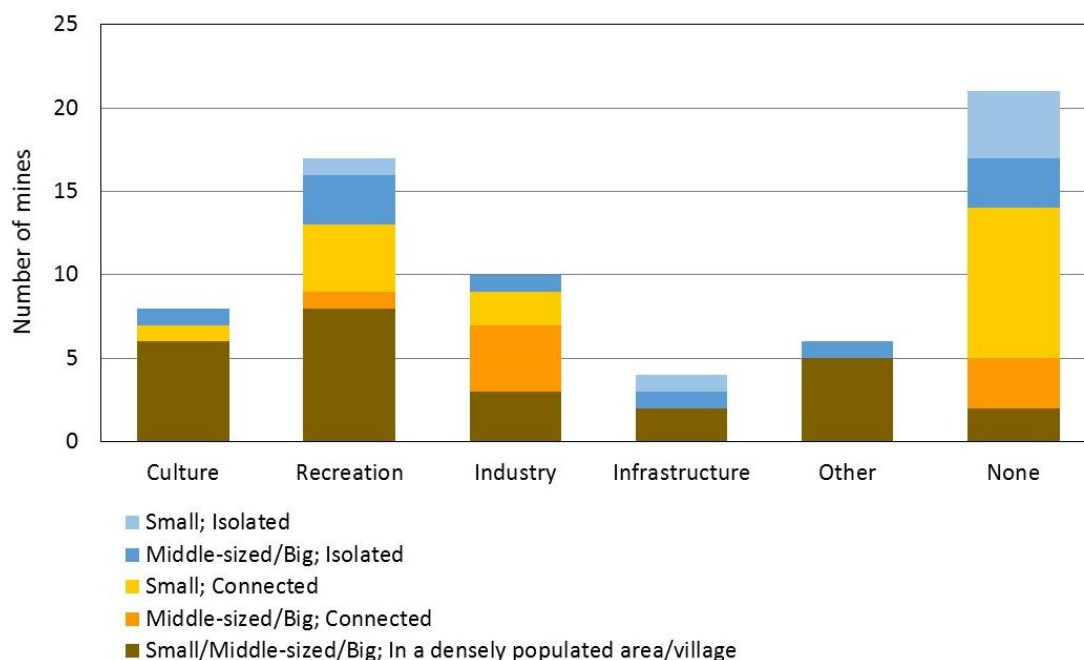
Table 1. Cont.

Culture & Recreation	Industry & Infrastructure	Other
<i>Tailings</i>		
<ul style="list-style-type: none"> <li>• Birdwatching<sup>28,46</sup></li> <li>• Motorsport venue<sup>47</sup></li> <li>• Rally/dirt biking track<sup>5, 21,25</sup></li> <li>• Shooting range<sup>3,25</sup></li> <li>• Golf course<sup>30</sup></li> <li>• Greyhound racing<sup>14</sup></li> <li>• Temporary parking lot<sup>25</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Concentration of ore<sup>20,41,48,49</sup></li> <li>• Airport (light aircraft)<sup>3</sup></li> <li>• Sand/gravel pit<sup>25</sup></li> <li>• Unofficial landfill<sup>25</sup></li> <li>• Waste water treatment plant<sup>37</sup></li> <li>• Waste facility of a potato processing factory<sup>28</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Military facilities<sup>51</sup></li> <li>• Raw materials research<sup>1</sup></li> </ul>
<i>Waste rock facility</i>		
<ul style="list-style-type: none"> <li>• Off-road driving<sup>19</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Construction material 3,4,8,20,27,28,36,37,45,47,48,50</li> </ul>	
<i>Water-filled open pit</i>		
<ul style="list-style-type: none"> <li>• Dive site<sup>3,5,7,12,14,19,25,36,45</sup></li> <li>• Concerts<sup>25</sup></li> </ul>		
<i>Underground mine</i>		
		<ul style="list-style-type: none"> <li>• Research on mine water treatment<sup>22</sup></li> </ul>
<i>Buildings</i>		
<ul style="list-style-type: none"> <li>• Restaurant<sup>5,30,36</sup></li> <li>• Museum<sup>30</sup></li> <li>• Observation tower<sup>30</sup></li> <li>• Protected building<sup>30</sup></li> <li>• Cultural events<sup>30</sup></li> </ul>	<ul style="list-style-type: none"> <li>• Concentration plant<sup>15,20,41,48,49</sup></li> <li>• Engineering works<sup>14</sup></li> <li>• Sawmill<sup>14</sup></li> <li>• Railway vehicle manufacturing<sup>28</sup></li> <li>• Lighthouse<sup>26</sup></li> <li>• Warehouse<sup>14</sup></li> <li>• Offices<sup>14</sup></li> <li>• Mushroom cultivation<sup>49</sup></li> </ul>	<ul style="list-style-type: none"> <li>• School<sup>30</sup></li> <li>• Military battle training<sup>9</sup></li> </ul>

### 3.2.2. Industry and Infrastructure

Nearly one third of the closed mining areas contained new activities related to industry and infrastructure (Table 1). A majority of these sites were big or middle-sized and located in the vicinity of densely populated areas or villages. New industries included a bus scrabyard [100], railway vehicle manufacturing [101], sawmill and engineering works [102] and a concrete element factory [103] in the closed nickel, iron, and copper mines. Old buildings were also utilized as warehouses and offices [101] and even for a short time for mushroom cultivation [103]. Closed iron mining sites included a waste facility of a potato processing factory [97] and a waste water treatment plant [104]. A mining tower used to serve as a lighthouse in an old iron ore mining island [105] and an airport for light aircraft was previously located in the tailings area of a zinc mine [106]. A concentration plant continued to operate in four sites [107–109]. Sand, gravel and rock (tailings, waste rock) were often utilized as construction material in the mining sites, local residential areas or for road building [59,60,73]. According to the

aerial photographs [67] and a recent study [59], over half of the post-mining sites included at least partially reforested areas or seedling/sapling stands. However, it was not possible to estimate the current or future potential of these areas as productive forest land.



**Figure 5.** Current or former post-mining activities in different types of mines. The mine size according to the total extraction: (1) small: <1 Mt; (2) middle-sized: 1–10 Mt; (3) big  $\geq 10$  Mt. Distance to the densely populated area or village: (1) in: 0–500 m; (2) connected: >500–5000 m; (3) isolated  $\geq 5000$  m. See Table 1 for more detailed description of land use classes. Industry: waste rock as construction material was excluded from the figure. Forestry use was not included in the analyses.

### 3.2.3. Other Re-Use

Other re-use of post-mining areas were found in 12% of the studied sites (Table 1). Military facilities were located in a closed copper and an iron mining site [93,99], fire rescue exercises were carried out in the vicinity of the tailings area of a closed gold mine [110], and a school was situated in an old building in the closed copper mining area [111]. Further, two research projects were located in the closed mining sites. One project examined potential of the tailings ponds of an old copper mine to be a source of secondary raw materials [112] and the other one the mine water treatment in a closed zinc mine [113].

### 3.3. Reopenings and Mineral Exploration

Reopening projects were under development in an iron ore mine closed in 1990 [73] and in a vanadium mine closed in 1985 [74]. Further, a silver mining site with an exploration tunnel constructed in 1988–1990 was currently under development [75]. In addition, re-opening plans were found for an iron mine closed in 1985 [114] and a gold mine closed in 2014 [115]. Exploration permits (or claims) had been applied or admitted for approximately half of the closed mining areas [63].

## 4. Discussion

### 4.1. Re-Use of Post-Mining Areas

Post-mining land use potential is a multidimensional issue which depends on environmental, technical, economic, social and cultural factors [40]. Mined land is inevitably altered to some degree



from minor disturbances to significant, extensive changes depending on the nature of a specific project [22,116,117]. An important question related to sustainability of mining legacies is what kind of post-mining land use activities are they able to support [31,49]. The decision for the most suitable land use(s) is driven by, for example, the characteristics of the area, expert opinions, the development plans of local communities and authorities, the legal environmental framework and the environmental restrictions [4,28,39,52].

If mining activities are carried out over an extended period of time, a significant mining community may develop in the area and post-mining land use can have a strong anthropogenic focus [28]. In Finland, closed mines were typically located in forest-dominated regions with relatively low population density. Post-mining sites located in the vicinity of densely populated areas or villages contained more cultural and recreational activities compared to sites further away from population centers. Former large mining communities classified as cultural heritage sites of national significance are examples of the sites with diverse post-mining functions such as museums, restaurants, leisure areas, and various events [79–86]. New mining projects, often with at least partially non-resident workers are not likely to result in similar type of traditional mining communities and architecture [97,118].

Globally, a range of industrial heritage tourism i.e., tourism at man-made sites, buildings and landscapes originated with historical industrial processes has been developed in old metal mines [36,45,119]. Industrial heritage tourism is typically dominated by the public sector and not for profit groups, and is often reliant on volunteers. Although it does not replace lost jobs of former mining industries, it can bring notable income to the area. Mining heritage tourism can also improve the image and reputation of former extractive regions that are not traditionally considered attractive visitor destinations [36,120].

The results showed that post-mining sites also included recreational activities that were not related to mining history. An example of this is a major motorsport venue built in the tailings area of a closed copper mine. Some post-mining sites were also important places for public (non-commercial) outdoor activities, such as birdwatching and scuba diving. In general, there is a growing interest in Europe and elsewhere to utilize open-pit mines for various purposes, such as aquaculture, aquatic sports and other recreation [35,47,121–125].

A post-mining area can be maintained as an industrial site if it is appropriate [22]. The result showed that post-mining sites, particularly in the vicinity of population centers included various industrial and infrastructural re-use. A concentration plant continued to operate in some mining areas, or mining sites were reutilized for a variety of local industries. Over half of the sites included reforested land resulting from plantation or spontaneous re-growth [59], but it was not possible to evaluate potential productive forestry use of these sites. However, it should be noted that a notable part of post-mining areas in Europe has been reclaimed to forest [126–128]. Further, cultivation of fast-growing tree species or natural woody vegetation in post-mining sites has been found to have substantial potential for bioenergy production [46,129].

Both closed and active mines can also provide excellent facilities for scientific studies. For example, underground mines have been utilized for research in physics, biology, geology and engineering (see e.g., [130,131]). In Finland, two of the closed sites included research related to secondary raw materials and mine water treatment [112,113]. In addition to closed sites, an operating copper and zinc mine Pyhäsalmi included underground research activities related to various physics experiments and other fields of sciences. The mine will be closed in the near future, and potential post-mining projects include a pumped-storage hydroelectric power plant and underground cultivation of plants [132,133].

Approximately 40% of closed mines did not include any significant post-mining activities (excluding construction material extraction or on-going reforestation). A major part of these mines were small, and some of them were satellite mines. In addition to site-specific characteristics, a distant location from a potential user group or market can affect land use activities in post-mining areas. Sometimes even an “out of sight, out of mind” attitude can apply, i.e., extraction sites closer to

populated areas are under greater pressure from society to be adequately reclaimed compared to remote sites [28].

In Finland, mine closure today is subject to administrative control and legal regulation. Statutory requirements derive from various statutes governing inter alia mining activity, environmental protection and waste management. The applicable legislation to a mining project with its own special characteristics is determined on case by case basis, examining whether the activity in question falls within the scope of a certain statute [134]. Mining licensing and environmental permitting usually require closure management plans in the early phase of the project. Regular updates to the plans and revision of the financial sureties for mine closure may also be required. Separate environmental permits and official closure management plans may also be needed during the final closure phase [135]. In addition to decommissioning the facilities and mine site reclamation to other sustainable uses, modern mine closure projects also include actions which aim at sustaining the socio-economic benefits of the mining operations and offsetting the negative impacts of mine closure within the local communities and environments [136].

#### *4.2. Restrictions and Hazards Related to Post-Mining Land Use*

Mining activities introduce various kinds of metals into a mine site itself and even far off soils and waters in potentially toxic quantities. Contamination by heavy metals or radiation in unreclaimed or inadequately reclaimed sites can significantly limit post-mining land use potentials [21,137,138]. Compared to metal mines, quarries (mines which produce building materials and dimensional stone) tend to have more versatile post-mining options, because they usually have less hazardous wastes and are located closer to densely populated areas [28,139,140]. The inventory of mining waste facilities in Finland showed that there are a limited knowledge on the current environmental state of many of the closed mining sites [58]. More detailed assessment of the further reclamation needs would be necessary in order to understand the potential risks related to various kinds of post-mining land use.

Post-mining activities resulting in breaking up and dusting of the ground contaminated by heavy metals can pose health hazards. For example, locals have used the unremediated tailings of an old gold-copper mine for dirt track biking, and the regional environmental authorities have recently prohibited this activity due to arsenic and copper contamination of the area [99]. For another example, health risks related to the use a tailings area of a closed molybdenum mine as a temporary parking lot during the events should be better evaluated [141]. According to a recent study, the utilization by the Finnish Defence Forces of the arsenic contaminated tailings of a closed copper-wolfram mine as a test field for explosives should also be given up in order to prevent dusting and the transport of particles to the surrounding areas [99].

Surface and/or groundwater contamination has been observed in the vicinity of many post-mining areas [58,59]. For example, the tailings of a closed copper-wolfram mine have been a major arsenic sources into the surface and ground waters. A recent study [99] suggest that swimming should be prohibited in the lake (Parosjärvi) located in the immediate vicinity of the mine, and groundwater wells for household use in the nearby area should be regularly monitored for potential arsenic contamination.

Sand, gravel and rock have been extracted from the old mining sites (tailings, waste rock) for construction purposes. However, more attention should be paid on the suitability of these materials particularly on residential and yard construction. For example, local heavy metal contamination of soils in residential regions outside the Outokumpu mining sites has probably resulted from mining waste utilized in house foundations [141].

Uranium mining pose particular challenges for remediation and future land use [138]. This study included one small uranium mine which was located in a remote forest landscape and remained abandoned for nearly three decades [142]. Although remediation measures took place later (including pine forest planting), a recent study [143] indicated that leaching and accumulation of radium from the waste-rock pile and possibly tailings is still ongoing.

In the case of underground mining, land subsidence is an important hazard that may cause large damages and threaten social and economic activities [144]. Recently, a sinkhole of approximately 600 m<sup>2</sup> opened up in the vicinity of residential buildings in a copper mining area closed in 1960 [145]. As land subsidence and sinkhole collapses can occur long after the mineral extraction has ended [146], these processes must be taken into account particularly in abandoned post-mining areas or sites where post-closure monitoring is no longer carried out.

#### 4.3. Future Mining Projects

A notable part of new mining projects do not result from new discoveries but the re-evaluation of previously recognized mineralization or orebodies which become economic under changed technological or market conditions [3,53]. Indeed, many mines have been opened and reopened on several times. Here, three re-opening projects were under development and at least two projects had recent development plans due to new ownerships.

It should be noted that characteristics of old and new mining projects can significantly differ from each other in terms of e.g., the mine size, estimated duration, mining methods and technologies (see for example [73]). Globally, the average size of mining projects has increased and ore grades declined [147]. This results in increasing amounts of waste rock removed, a larger volume of tailings and more extensive disturbed areas, particularly in the case of open-pit mines [50,56,148]. This also means that future post-mining land use potential can significantly differ from the current situation in the closed mining area. Opinions on reopening of a mine can notably differ between various stakeholders depending on e.g., their current source of livelihood and relations to areas located in the vicinity of the mine [149,150].

A timely example of the increasing mine sizes is the planned reopening of the Hannukainen iron mine in northern Finland [73]. Between 1978 and 1990, iron ore was mined from two open-pits of about 16 ha and 5 ha. The possible re-opening of the mine would include the establishment of two open-pits of 200 ha and 55 ha (see Figure 4). The mining concession area of nearly 30 km<sup>2</sup> would also include a concentration plant, large waste facilities and other infrastructure located in the closed Hannukainen and Rautuvaara iron mining sites and their surroundings. It has been estimated that the active mining period would last 17–25 years, after which mine closure would take approximately five years and monitoring the next 30 years [151]. Expanding spatial and temporal boundaries of the mining projects pose new challenges to estimating the extent and magnitude of environmental changes, understanding social and economic impacts on different stakeholders and planning future sustainable post-mining areas.

Half of the closed mining areas examined here were applied or granted for an exploration permit (or claim), which gives the right to explore the structures and composition of geological formations, and provides the holder with a privilege for the mining permit, which in turn provides the right to exploit the deposit [152]. This shows that post-mining areas and their surroundings often contains expectations or aims towards potential new mineral extraction in the future. Generally, only a few exploration projects will result in the opening of a mine. However, active exploration can have important impacts on perceptions and expectations of the future development of the region (positive or negative) by local communities and the public in general [153].

## 5. Conclusions

Post-mining sites in Finland contain a wide variety of physical and human environments. Significant mines located near population centers seemed to support the greatest diversity of post-mining activities related culture, recreation, industries and infrastructure, whereas new functions in small and/or isolated sites were generally limited. Sustainable re-use of post-mining areas requires efficient evaluation of land use potentials and limitations and the overall suitability of the sites for local land use needs. Increasing sizes of new mining projects calls for paying more attention on the characteristics and functions of the future post-mining landscapes to avoid negative land

use development leading to degraded and underused areas from environmental, economic and social perspectives.

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