Guidelines for volcanic ash recovery and valorization

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Volcanic ash (VA) from Mt. Etna (Sicily, Italy), the largest and most active volcano in Europe, is produced during explosive activity and its release into the surrounding areas causes air contamination, infrastructures and buildings damages and transport systems disruption (Cai et al., 2016). Moreover, frequent eruptions (lasting from a few weeks to months) cause ashfall in downwind areas with depositions of different thickness into urban areas and, consequently, detrimental effects on cities economy due to clean-up operations linked with road system and public areas (Contrafatto, 2017). Furthermore, the release of VA is a persistent problem for air navigation causing the close of near airport of Catania-Fontanarossa. After deposition on the road, VA is conventionally classified as waste (code 200303 or code 170504 of the European Waste Catalogue) and its fate is often landfilling, which represents an uneconomic and unsuitable choice due to the large space required and costs related to transport and disposal. However, due to recent Etna activities characterized by ash plumes, fountaining, and lava flows occurred between December 2020 and March 2021, municipalities of the surrounding areas have had to involve greater economic resources to face the problem linked to ash depositions. Moreover, according with the "end-of-waste" criteria, the recycling of volcanic ash is recently encouraged by local authority. Many experimental studies have investigated the use of volcanic ash in different engineering fields. VAs have been used as alternative material at cement replacement (Contrafatto, 2017) and to develop novel geopolymers (Luhar et al., 2019). Other applications deal with mortar production, novel ceramic materials, soil stabilization and high strength concrete (Belfiore et al., 2020; Cai et al., 2016; Contrafatto, 2017). In the field of water and wastewater treatment, VAs have been used as supportive precursor for the preparation of photocatalytic composite (Lum et al., 2020). Although the mineralogy of VA depends on eruption type, previous studies have demonstrated that VA mainly consists of an amorphous aluminosilicate glass. This mineralogical composition makes VA a suitable raw material in the synthesis of zeolites (Belviso et al., 2021).

The Italian Law 29 July 2021, n. 108 "Simplification measures for the promotion of the circular economy" has recently regulated the recovery of volcanic ash that will not be considered waste if used to replace raw materials within production cycles, using processes or methods that do not damage the environment or endanger human health. Therefore, the purpose of this study that was carried out within the REUCET Project was the development of Guidelines for the recovery of volcanic ash from Mt. Etna for several applications in the field of civil and environmental engineering. The first phase of the Guidelines involves the identification of production cycles in which volcanic ash can be used to replace raw materials through methods and processes that do not cause damage to the environment or health. Based on the activities carried out within the REUCET Project, the production cycles in which the appropriate use of volcanic ash has been demonstrated are indicated below. These production cycles can fall within the perspective of the circular economy fulfilling the Law 29 July 2021, n. 108.

- Use in construction for the production of cement conglomerates and insulating products:
    - production of plasters with grain size fraction from 1 mm to 9.5 mm;
    - production of lightweight and insulating mortars with a grain size fraction from 1 mm to 9.5 mm.
- Production of lightweight ceramic tiles, such as "Cotto Siciliano" through the use of the ash fraction < 1 mm. The products have good physical-mechanical characteristics and are approximately 20% lighter.
- Building the deeper layers (foundation, subgrade) of road pavements of minor roads: volcanic ash of various grain sizes (up to approximately 10 mm), although presenting problems such as the fragility of the grains and extreme porosity, if suitably compacted are successful to achieve good lift levels.
- Development of innovative materials for the removal of contaminants from air and water starting from volcanic ash < 1 mm in size:
    - photocatalytic composite materials made with silica airgel and titanium dioxide for the removal of organic contaminants in air or water via photocatalysis with natural or artificial light;
    - synthesis of zeolites via hydrothermal process for the removal of ionic compounds (e.g. Cs^{+}, NH_4^{+}, Ca^{2+}, Mg^{2+}) from drinking or waste water via ion exchange.

As previously described, the applications of Etna volcanic ash tested in the REUCET Project require volcanic ash with specific grain size for the identified production cycle. Furthermore, volcanic ash collected from public and private surfaces still requires screening to remove foreign bodies (plastic, leaves, paper, etc.). Therefore,

a screening phase is required which has the dual purpose of removing foreign material and classifying the collected ash by grain size appropriate to the different production cycles. It should be highlighted that although the grain size of the ash deposited on urban areas depends on the specific eruptive event and the distance of the urban area from the volcanic cone, the ash collected from road surfaces generally has a grain size of approximately 1 mm or less due to the passage of vehicles that crush the ash. Figure 1 shows the flow diagram for the application of the Guidelines, which indicates the phases of recovery and use of Etna volcanic ash taking into account the production cycles tested in the REUCET Project.

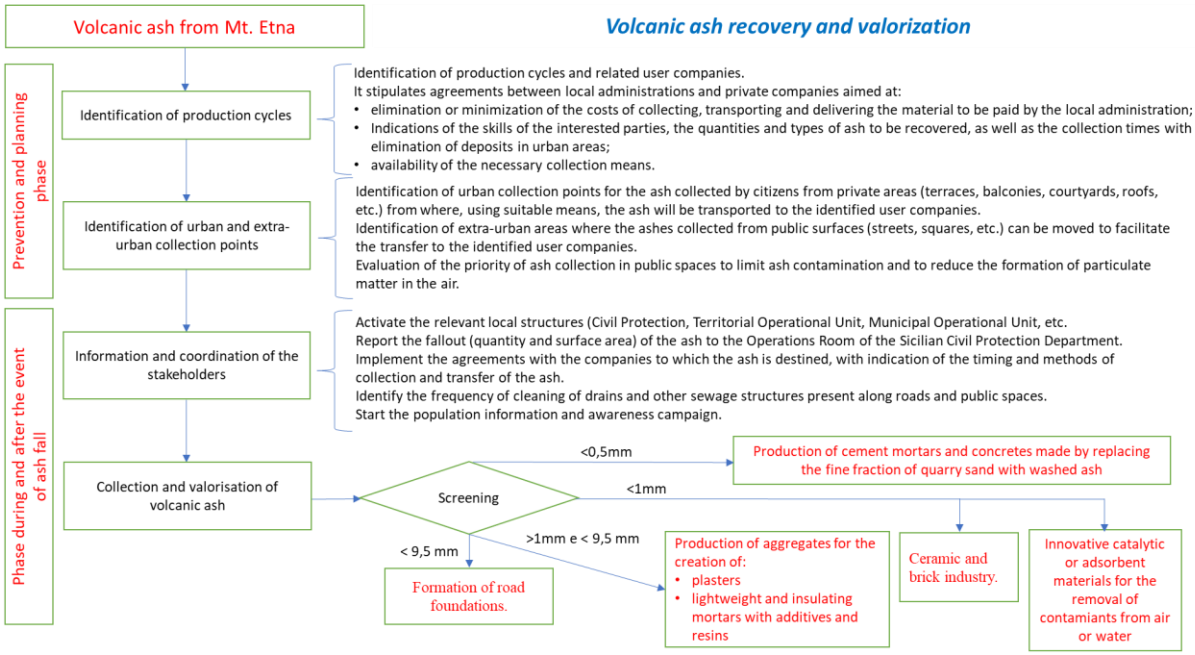

Figure 1. Fow diagram for the application of the Guidelines for recovery and use of Etna volcanic ash.

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