ALLIANCE FOR
RESPONSIBLE MINING

# Reduction of the Carbon Footprint in **Artisanal and Small-scale Mining (ASM) in Colombia and Peru**

**Opening date:**
**July 2024**

**End date:**
**July 2025**

Executor:

**Alliance for Responsible Mining**

Donor

**Scotiabank Net Zero Research Fund**

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# Project Objective

The main objective of the project was to generate technical and applied knowledge on reducing the carbon footprint of artisanal and small-scale mining (ASM) operations by identifying, analyzing, and implementing good environmental practices. The aim was to advance the decarbonization of the ASM sector through the design of energy efficiency strategies, waste management, environmental rehabilitation, and the use of renewable energy, supported by financing mechanisms to facilitate their adoption. The initiative involved measuring and analyzing the carbon footprint of eight mining units in Colombia and Peru, as well as the pilot implementation of a reduction plan in one of them, using a tool developed by ARM.

A blog post has been published to share the research at the following link: Visit the blog here.

ACRONYMS

ARM - Alliance for Responsible Mining GHG - Greenhouse Gases
ASM - Artisanal and Small-scale Mining
ASMO - Artisanal and Small-Scale Mining Organization

# Expected results

With the implementation of the project, it was expected to:

- Consolidate technical evidence on ASM GHG emissions, helping to close a critical information gap. Scope 1, 2, and 3 emissions were measured and analyzed in small-scale gold mining operations, enabling quantification of their climate impact and supporting evidence-based interventions.
- Identify and implement viable mitigation practices aligned with the Just Energy Transition, such as energy efficiency, sludge utilization, reforestation, and waste management. These measures proved to be technically feasible and scalable, laying the groundwork for future decarbonization investments.
- Design and validate a replicable pilot model for carbon footprint reduction that integrates diagnosis, implementation, and monitoring of sustainable actions. Tested in a real operation, this model can be adapted by other mining units seeking to progressively and measurably reduce their environmental impact.
- Gain key technical knowledge from the pilot energy audit, which identified concrete opportunities to optimize conventional energy use.

# Expected results

- The ARM portfolio of climate change tools was expanded and strengthened by integrating new methodologies for calculating carbon footprints, analyzing mitigation opportunities, and developing green financing proposals, all aligned with the Forest Smart Mining strategies and water footprint initiatives.

# Challenges to overcome

Among the main challenges were:

- The limited/poor availability of information on $CO_2$ emissions in gold ASM and emission management tools and methods for reducing them.
- The technical and financial constraints of small-scale mining operations to implement $CO_2$ emission mitigation measures.
- The need to generate long-term, sustainable community ownership of the actions and mechanisms proposed for the reduction of $CO_2$ emissions.
- Difficulties in accessing funding sources and mechanisms for the implementation of actions adapted to the ASM reality.

# I. What were the key findings of your research?

Optimization of Optimization of energy consumption and reduction of operating costs

The energy audits conducted showed that the incorporation of high-efficiency technologies - such as IE3+ motors, advanced control systems and smart boards - has the potential to generate energy savings of 10% to 30% in certain operations. These results imply a direct decrease in operating costs and also generate substantial reductions in $CO_2$ emissions associated with the consumption emissions associated with the consumption of emissions associated with energy consumption, demonstrating a strategy with a double impact: economic and environmental.

Progress towards a circular economy in solid waste

The application of circular economy principles made it possible to identify concrete opportunities for the reuse of waste rock in mining infrastructure works, such as roads and retaining walls.

This practice allows:

- The reduction of the volume of waste sent to final disposal.
- The reduction of associated environmental impacts.
- A paradigm shift in waste management of materials, transforming a liability into a usable resource.

**Increased carbon sequestration through restoration**

Pilot reforestation and bioremediation plans implemented in degraded areas contribute to both landscape and ecological restoration, as well as to carbon sequestration. In the medium term (up to five years), this vegetation cover could offset between 10% and 15% of the total estimated emissions from the mining operation, integrating compensation as an active decarbonization strategy..

**Energy efficiency and electricity use (Scope 2)**

It was identified that electricity consumption from the National Interconnected System accounts for only 9% of the total carbon footprint. The energy audit highlighted good practices already in place, such as the use of high-efficiency motors and rational operational measures, confirming that this aspect does not represent a critical weakness, although there is still room for optimization and substitution with renewable energy sources.

**Optimization of water and wastewater management**

The installation of wastewater recirculation and treatment systems by means of through The installation of recirculation and wastewater treatment systems using artificial tanks significantly reduced the pollutant load, ensuring compliance with regulatory parameters and minimizing the impact on receiving water bodies. These measures also reduced fresh water consumption by more than 40%, reinforcing the responsible use of this critical resource.

**High Potential for Renewable Energy in the Country**

The climatic and structural conditions observed at the mining operation present a favorable scenario for the installation of solar energy systems in the processing plants and directly at the mines. This opportunity could significantly reduce Scope 2 emissions, enhance energy autonomy, and increase resilience against interruptions or fluctuations in electricity supply costs.

**Predominant Indirect Emissions (Scope 3)**

The analysis revealed that Scope 3 emissions represent 82% of the total footprint, mainly linked to:

a) Waste generation: Especially sludge with potential for use as a substrate in bioremediation and revegetation, after complying with analysis and conditioning processes.
b) Supply chain: Chemical inputs and raw materials transported over long distances, with a significant weight of emissions associated with transportation and logistics.

This finding highlights the need to address decarbonization beyond the direct limits of the operation.

**Hazardous waste management in risk contexts**

Hazardous waste whose external management is limited by the absence of safe collection routes, due to public order problems, was detected. In view of this barrier, we propose strengthening internal safe storage and treatment practices as a temporary measure to prevent environmental and health risks, while viable logistical solutions adapted to local contexts are managed.

**Significant costs for decarbonization**

The estimated investment to implement the key actions of the decarbonization plan is around USD 100,000 per small-scale mining operation. While this figure represents a challenge for artisanal and small-scale operations, it also puts into perspective the need to access financing mechanisms, fiscal incentives and strategic alliances that make the transformation feasible within a horizon of approximately two years.

**Long lead times for the implementation of improvement actions**

Several actions contemplated in the path to carbon neutrality require extended timeframes. The adoption of clean energy depends on technical procedures and external authorizations that can take between 6 and 12 months. Likewise, the remediation and revegetation processes require multiple phases -soil analysis, improvement of physicochemical conditions, undertaking and revegetation- whose benefits in carbon sequestration are only fully visible after five years of vegetation cover maturation.

# II. How did the knowledge gained from your research impact your organization and target audience?

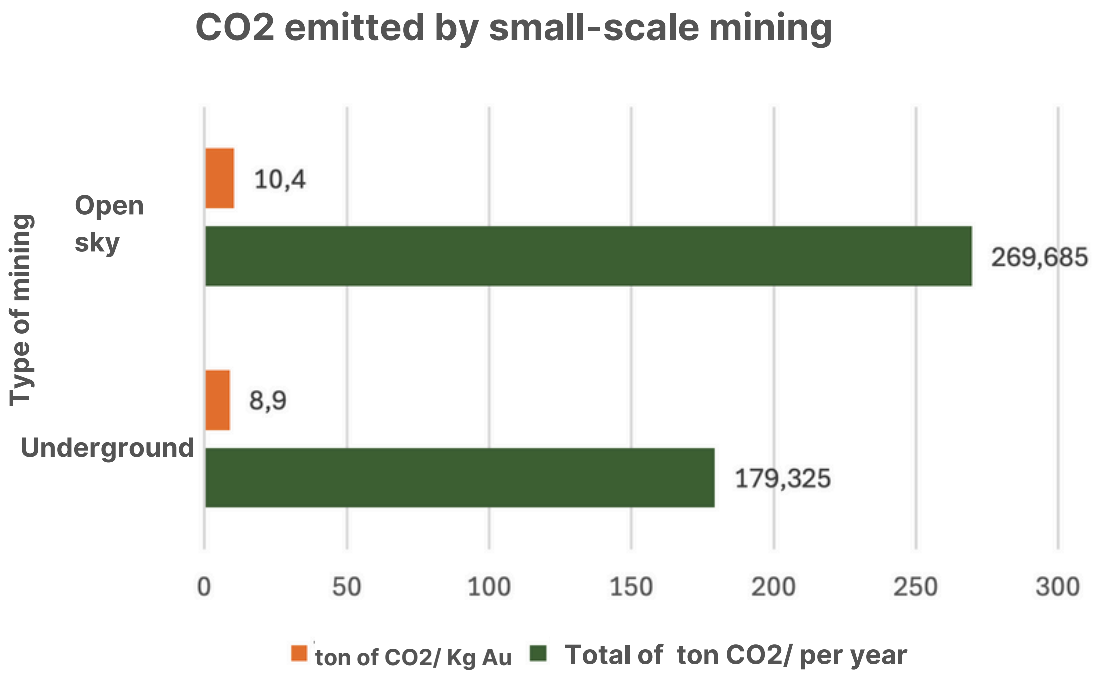
The research on carbon footprinting in artisanal and small-scale mining (ASM) generated a body of high-value technical, operational and strategic knowledge, with direct direct applications a organizational level and potential for replication in the global mining sector.

This knowledge generated practical tools for decision making, planning, and implementation of decarbonization-oriented actions in ASM.

From the technical point of view, we were able to accurately map the main sources of greenhouse gas (GHG) emissions at the operations, differentiating direct emissions (Scope 1), indirect emissions from electricity consumption (Scope 2) and other indirect emissions from the value chain (Scope 3). This detailed diagnosis made it possible to design evidence-based mitigation strategies, which include the adoption of energy-efficient technologies, harnessing the potential of renewable energies, recirculation and efficient use of water, responsible waste management and ecological restoration of degraded areas.

| Scope 1 | Scope 2 | Scope 3 |
| --- | --- | --- |
| • Gasoline<br>• Diesel<br>• Natural Gas<br>• Propane Gas<br>• Light Oil<br>• Heavy Fuel Oil | • Use of electricity to power all electrical equipment in the mine and processing plant. | • Use of chemicals<br>• Quality of water discharged from the operation<br>• Waste generation, including hazardous waste<br>• Worker displacement<br>• Displacement and sale |

At the sectoral level, the research provided unprecedented data by calculating the carbon footprint of eight mining organizations in Colombia and Peru, allowing comparison points to be established according to operating conditions, type of mining, production volume and number of workers. This comparative analysis laid the groundwork for defining common practices that, once adopted, could significantly reduce the carbon footprint and serve as a replicable model for other mining units interested in moving towards carbon neutrality.




It was possible to identify commonalities among ASMOs, which led to clear research directions that can be applied to scale up small-scale mining activities. In this way, strategies for reducing emissions and promoting the decarbonization of these activities were developed. The strategies investigated within the framework of the project are presented below, along with an estimation of the potential percentage reduction that could be achieved if implemented at 100%.

| Strategy | Summary action that reduces impact and footprint | Estimated % footprint reduction |
|---|---|---|
| **1. Energy Efficiency** | Implementation of audits, process optimization, predictive maintenance and clean technologies (solar panels, efficient motors, etc.). | 20% a 50% |
| **Waste Management** | Implementation of circular economy, composting of organic waste and minimization of hazardous waste (reuse, sorting and recycling). | 15% a 30% |
| **3. Environmental Restoration** | Reforestation, soil conservation, bioremediation of contaminated soils, and restoration of degraded ecosystems. | 25% a 35% |
| **4. Community participation** | Environmental education, co-management, governance models, and adoption of sustainable behaviors by workers and communities. | 5% to 15% (indirect, through cultural change) |
| **5. Substance Management (Mercury and chemicals)** | Elimination or reduction of mercury and cyanide use, adoption of clean technologies, safe handling protocols and contaminant recovery. | 50% a 90% |
| **6. Rational Use of Materials** | Choice of durable inputs, precision technologies, in-house recycling, efficient water management and life cycle analysis | 20% a 40% |
| **7. Wastewater Management** | Implementation of artificial wetlands, wastewater treatment and recirculation systems, and continuous monitoring. | 30% a 60% |

At the organizational level, the knowledge generated crystallized in the formulation of a Decarbonization Plan, aligned with international standards such as the GHG Protocol and the Sustainable Development Goals (SDGs). This plan strengthened the organization's environmental planning capacity and regulatory compliance, as well as improved its competitive positioning in the face of the sustainability requirements of global markets, opening up opportunities to access certification and green financing schemes.

| | |
|---|---|
| Energy Audit | • Energy consumption assessment of equipment<br>• Identification of energy waste points<br>• Proposal for equipment replacement, operational improvement opportunities, and energy savings |
| Renewable energies | • Identification of solar electromagnetic radiation<br>• Design of a photovoltaic system<br>• Connection to the local electrical grid<br>• Use of clean energy |
| Water management | • Quantification of the amount of water used in the mining process<br>• Proposal for water recirculation and reduction in water consumption<br>• Quality of effluent discharge |
| Waste management | • Identification of types of waste generated<br>• Reduction plan, including waste reuse<br>• Final waste disposal |
| Substance management | • Identification of substances used<br>• Proposal for reduction/substitution |
| Transportation | • Transportation of personnel, ore, and gold sales<br>• Proposal for reducing transportation / use of biofuels |
| Reforestation | • Identification of recovery/reforestation areas<br>• Soil analysis, species identification, and reforestation process design<br>• Reforestation monitoring |

Finally, the research moved from theory to action with the selection of the "Los Conquistadores" mining operation, located in the department of Cauca, Colombia, as a pilot case. This pilot represents a living laboratory where some energy efficiency, fuel substitution, circular waste management and revegetation actions were implemented, with the objective of measuring in real time their impact on the carbon footprint. This step benefits the organization directly involved, and constitutes a reference for ASM in the region, demonstrating that it is possible to make mining productivity compatible with climate responsibility and setting a replicable precedent towards a future of low-emission mining operations.

**Description of the pilot at the Artisanal and Small-scale Mining Organization (Organización de Minería Artesanal y de Pequeña Escala -OMAPE)**

The selected mining operation has a family origin, with ties rooted in the territory for more than 50 years. Initially, mining was carried out in an artisanal and low-tech manner. Over time, the family has managed to consolidate a mining operation with a business approach. Since 2016, they have been advancing labor, accounting, administrative and financial formalization processes, in articulation with mining formalization mechanisms through operating contracts.

| | | | | | | |
|---|---|---|---|---|---|---|
| **Name of the mine:** | Los Conquistadores | | **Country:** | Colombia | **Department:** | Cauca |
| **Type of mining:** | Subway | | **Municipality:** | Buenos Aires | **Vereda/Site:** | Loma Alta |
| **Number of workers:** | 43 | **Men:** | 39 | **Women:** | 4 | |
| **Work shifts:** | 2 | **Days worked in the month:** | | | 26 | |
| **Name of the plant:** | Los Conquistadores | | **Owned/rented:** | | Owned | |
| **Product:** | Gold | Concentrate | **Quantity:** | 6 | **Kg/year** | |

The Los Conquistadores operation contract has 2 mine entrances; Bocamina La Leche and Guaudal. The latter is not in activity. The ore extracted from these mineshafts is transported by dump trucks to the company's plant, where the ore is processed by crushing, grinding, concentration and flotation. The distance the dump trucks travel from the La Leche mine to the plant is 10 km.

*Los Conquistadores Processing Plant*
*Coordinates: 2,9839820*
*-76,6507771*

*Mina La Leche – Los Conquistadores.*
*Coordinates: 02º58´30" N -76º39´30" W*

Additionally, at the territorial and social level, the results of the research provided fundamental elements for dialogue with communities, environmental authorities and other stakeholders. By making visible the real impacts of mining activities and the opportunities for improvement, spaces of trust, participation and co-responsibility will be generated. This translates into the strengthening of practices such as environmental education, communication of results, adoption of environmental performance indicators and the active search for climate finance sources. In summary, the research process allowed strengthening the technical tools for measuring and reducing the ASM carbon footprint, and showed that it is possible to promote an organizational and cultural transformation aimed at responsible, low-carbon and socially legitimate mining. The lessons learned lay a solid foundation for the replicability of these actions in mining units, paving the way for a just and sustainable transition in the sector.

# III.Did your findings match your hypothesis? Why yes or why no?

**Assessed Hypothesis**

Artisanal and small-scale gold mining can demonstrate its commitment to the environment and the reduction of its carbon footprint by implementing environmental management actions and strategies. These can be identified, evaluated and prioritized by analyzing emissions data and reviewing practices in selected organizations and under real operating conditions.

The results of the research confirm that, in Artisanal and Small-scale Mining (ASM), it is feasible to identify and implement actions aimed at decarbonizing the activity, thus contributing to the reduction of environmental impacts, the protection of ecosystems and the reduction of the carbon footprint as a contribution to climate change mitigation.

However, most of these actions are still in a mainly theoretical phase because, due to the time required for the adoption of the practices, it was not possible to implement all of the planned strategies or to evaluate their long-term results under real operating conditions.

The main milestones achieved in the pilot include:

- Emission reductions: An approximate CO2 reduction of 5,880 kg$CO_2$eq is projected for 2025 thanks to actions such as integrated waste management, soil recovery through bioremediation, installation of orchards with organic waste utilization, and improvements in energy operating practices.
- Technical design for the use of solar energy: A viable plan was structured for the installation of a photovoltaic system with the capacity to supply 100% of the mining operation's electricity consumption, which would allow a progressive transition to renewable sources.
- Reforestation and soil restoration: A pilot project was launched for the ecological recovery of degraded soils, using innovative materials such as recycled hair mats, and there are plans to plant 200 native species with the potential to capture 2 tons of $CO_2$ per year.

- Small-scale sustainable production through community gardens: A 10 m² garden was implemented within the mining area, fed by compost produced from the recycling of organic waste. This action not only promotes self-consumption and food security, but also avoids the emission of approximately 3,840 $kgCO_2eq$ per year.
- Organizational and community transformation: The environmental culture within the organization was strengthened through awareness campaigns, environmental education and appropriation of good sustainable practices by workers and communities.

These advances position the organization as a replicable model for other ASM operations. The implementation of the plan has demonstrated that it is possible to move towards carbon neutrality through progressive, technically and financially viable actions, adapted to small-scale mining contexts.

In practice, although mining activity has an obligation to responsibly manage the impacts of its operations, such practices are not always continuous or fully conscious of the natural resources affected.

This demonstrates the need to establish mechanisms and incentives that allow mining organizations to adopt clean technologies, incorporate responsible environmental practices and, in turn, perceive tangible benefits derived from their implementation.

The materialization of these actions requires the concurrence of several key factors: availability of economic resources for the acquisition of more sustainable technologies, adequate timeframes for the adoption and monitoring of new practices, training and capacity building in environmental management and methodologies for the decarbonization of mining.

Consequently, the findings obtained are theoretically aligned with the initial hypothesis. It is expected that in subsequent phases and over a longer time horizon, the full adoption of decarbonization strategies will confirm this alignment.

The recommendation generated at the end of this project is the reconfiguration of the timeframe foreseen for the implementation of the Environmental Management Plan with a focus on decarbonization of ASM.

This will allow the requirements to be adapted to the operational, technical and socioeconomic realities. It is essential to maintain continuous support to ASM throughout the process, continuing with technical assistance for the effective adoption of the proposed actions, strengthening local capacities and ensuring periodic monitoring of progress. This monitoring should include the measurement and evaluation of the carbon footprint, in order to verify the results obtained, make timely adjustments and consolidate a process of continuous improvement towards more sustainable and low-emission mining operations.

# III. What challenges did you encounter during your research project and how did you overcome them?

**1. Lack of methodological standardization to measure emissions.**

*Challenge:* The absence of a unified methodology for measuring the carbon footprint in small-scale mining makes it difficult to quantify the amount of Greenhouse Gases - GHG emitted by this activity, in addition to not having clear guidelines aimed at reducing and eventually decarbonizing the activity.

*Solution:* The GreenHouse Gas Protocol approach was adopted, adjusted to the national context through the guidelines of the Comprehensive Climate Change Management Plan for the Mining-Energy Sector - PIGCCme, which made it possible to obtain a coherent and technically valid baseline for the calculation of Scope 1, 2 and partially Scope 3 emissions.

**2. Lack of knowledge of operating ASM personnel about the environmental approach.**

*Challenge:* There was evidence of a low appropriation of the concepts of environmental sustainability and carbon footprint among ASM operational staff, which generates resistance to the implementation of mitigation measures.

*Solution:* An awareness-raising and training plan was designed with a technical-practical focus, highlighting the economic benefits of energy efficiency, climate change mitigation actions and environmental compliance, which increased the level of internal acceptance.

**3. Economic constraints for the full implementation of the strategic environmental management plan.**

*Challenge:* The implementation of activities for the transition to photovoltaic energy and the management of the use and final disposal of hazardous waste require a high budget investment due to the geographic conditions of the area and social dynamics.

*Solution:* The process of collecting, storing and separating hazardous and usable waste was optimized in order to mitigate environmental risks, reduce waste generation and reduce the impact generated by waste. Also, with the results of the energy audit, actions were planned to reduce and optimize electricity consumption at the plant and mine.

**4. Safety issues in the territories that do not allow the implementation of actions in a standardized manner.**

*Challenge:* In the region where the pilot for the implementation of the decarbonization plan was planned (Cauca, Colombia), there are armed groups, which makes it difficult to access any type of external intervention.

*Solution:* Hand in hand with the mining organization, some joint accompaniment visits were established, where local operators could accompany the complete tours of the external personnel that went to perform the energy audit, socialization on climate change and evaluation of the sites for the installation of infrastructure for the generation of clean energy.

**5. Limitations in areas with the carbon sequestration capacity of the forestry component and green areas of the mining organization.**

*Challenge:* Both the area of the mill and the mining operation have few areas for planting plant species that would help offset carbon emissions.

*Solution:* Revegetation quadrants are planted in areas destined for the final disposal of sludge and the soil bioremediation process is initiated to recover essential components that the plants physiologically require for their development.

**Despite these challenges, the project was able to consolidate a comprehensive environmental diagnosis of the mining operation, identify opportunities for improvement and propose concrete measures to reduce greenhouse gas emissions, aligned with the sector's carbon neutral goals for 2030.**

# V.What surprised you most about your project and research findings?

1. The widespread underestimation of indirect emissions (Scope 3) within mining operations. Because of the large use of fuels in mining, as well as the equipment required for the mining operation and the operation of the beneficiation plant, it was expected that the largest emissions would be from the other scopes. the research revealed that more than 80% of total emissions were associated with indirect factors such as the supply chain, use of explosives, waste disposal and consumption of external inputs.
2. The real reduction potential of certain operational strategies when applied in an integrated manner makes it possible to demonstrate a reduction in greenhouse gas emissions, as well as to compensate for emissions that can no longer be reduced in the operation as such. As described above, with the implementation of appropriate actions, a reduction in GHG generation will be achieved in each of the actions evaluated.

3.The existence of an effective alternative for their compensation called the purchase of Renewable Energy Certificates (RECs). The purchase of these certificates allows an organization -in this case, the mine or plant- to attribute to its own electricity consumption a clean generation, reducing its carbon footprint in a verifiable and traceable manner. In Colombia, RECs are managed through ECOGOX, the Renewable Energy Source Certification Ecosystem, operated by XM, the administrator of Colombia's National Interconnected System. ECOGOX is aligned with the international I-REC standard and allows for the issuance, traceability and retirement of certificates to ensure that each renewable energy unit is only counted once. Companies can purchase RECs directly on the platform or through authorized traders, choosing between different technologies (solar, wind, hydro, etc.), geographic zones and generation periods.

# VI. How will the local, regional or global community benefit from this research in relation to advancing the transition to a zero net emissions future?

This research is a strategic contribution to accelerate the transition to a sustainable and decarbonized mining model, generating tangible benefits at the local, regional and global levels. Through the detailed analysis of greenhouse gas emissions in ASM, the main emitting sources and the most relevant opportunities for their mitigation have been accurately identified.

This knowledge allows guiding the implementation of concrete measures such as energy efficiency in machinery, process electrification, control of fugitive emissions and optimization of waste management, strengthening the relationship with neighboring communities, improving environmental indicators and fostering an organizational culture committed to climate action.

At the regional level, the results offer a roadmap that can be replicated for other mining units, serving as a reference for the design of environmental management plans with progressive and realistic carbon goals. This methodology encourages the integration of international sustainability standards in the mining sector, promoting circular economy practices and strengthening the articulation with green value chains. The transfer of this model to different regional contexts favors the homogenization of good practices and the creation of synergies between mining actors, environmental authorities, communities and technical support entities.

The findings are directly aligned with the climate commitments established by Colombia and other mining countries in the framework of the Paris Agreement. The technical evidence generated contributes to the development of sectoral decarbonization strategies and the validation of specific methodologies for the quantification of carbon footprints in extractive activities, a field that still has significant information gaps. In this way, the research strengthens the scientific and technical basis necessary to support public policies and actions oriented towards a future of zero net emissions.

In summary, this research promotes environmental innovation in the mining sector, and positions ASM and mining in general as strategic actors in the fight against climate change. It demonstrates that it is possible to make mining productivity compatible with climate responsibility, laying the foundations for a just and sustainable transition that benefits local communities, energizes the regional economy and contributes to global climate goals.

## Once the research is completed, what are your next steps to continue or maximize the impact of this work?

The next step will be to continue accompanying the mining organization in which the pilot of the Decarbonization Plan was developed, to continue with the measurements of the feasibility of carbon neutrality in ASM under real operating conditions.

This process will include close monitoring of the implementation of the prioritized actions, ensuring that the emission reduction targets are met and verifiable.

Within this support, the progressive adoption of technologies for the generation of clean energy, the optimization of waste management, the substitution of fuels for alternatives with a lower carbon footprint, and the implementation of revegetation programs in degraded areas as a compensation measure will be promoted. These interventions will be aimed at demonstrating, with data and evidence, the effective reduction of emissions in the mining operation.

In parallel, we will seek to replicate the actions and lessons learned from this research in leading mining units that currently comply with responsible production standards, but that, through this decarbonization approach, could further strengthen their environmental performance and reputation in the market. This work will allow validating the scalability of the model and its applicability in different production contexts.

Finally, the transfer of these practices to other mining units interested in demonstrating the decarbonization of their operations will be promoted. This process will include training activities, technical assistance and the generation of strategic alliances, to broaden the scope of the results, consolidate collaboration networks and contribute more broadly to the transition towards a low-emission and environmentally responsible mining industry.


Web Site:

**www.responsiblemines.org**

E-mail:

**arm@responsiblemines.org**



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