



**Food and Agriculture
Organization of the
United Nations**

Overview of the biochar sector in Viet Nam and the AI4Biochar tool

Technical report

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by

Alessandro Flammini, Giulia Conchedda, Do Xuan Lan, Marco Colangeli, Lorenzo Testa,
Francesco Tubiello and Maria Michela Morese

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Inputs and technical review from:

Minh Phuong Do (FAO National Expert), Vu Duy Linh (FAO National Expert), Duc Huy Dinh (Vietnamese Ministry of Agriculture and Environment), Nguyen Song Ha (FAO Viet Nam), Michelle Piccoli (FAO), Leon Casse (FAO) and Furkan Celik (University of Twente).

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Abbreviations

ADB	Asian Development Bank
ASEAN	Association of Southeast Asian Nations
B4SS	Biochar for Sustainable Soils
BEFS	Bioenergy and Food Security
BWG	Biochar Working Group
CDR	carbon dioxide removal
CO ₂ eq	carbon dioxide equivalent
DCP	Department of Crop Production
DFAT	Australian Department of Foreign Affairs and Trade
ESS	Statistics Division (FAO)
FAO	Food and Agriculture Organization of the United Nations
GBEP	Global Bioenergy Partnership
GCF	Green Climate Fund
GEF	Global Environment Facility
GHG	greenhouse gas
GIS	geographic information systems
IFPRI	International Food Policy Research Institute
ILO	International Labour Organization
IPCC	Intergovernmental Panel on Climate Change
ITC	Faculty of Geo-Information Science and Earth Observation, University of Twente
JICA	The Japan International Cooperation Agency
LCA	life cycle assessment
MAFF	Ministry of Agriculture, Forestry and Fisheries (Japan)
MARD	Ministry of Agriculture and Rural Development (Viet Nam)
MAE	Ministry of Agriculture and Environment (Viet Nam)
MOET	Ministry of Education and Training (Viet Nam)
MOF	Ministry of Finance (Viet Nam)
MOIT	Ministry of Industry and Trade (Viet Nam)
MONRE	Ministry of Natural Resources and Environment (Viet Nam)
MOST	Ministry of Science and Technology (Viet Nam)
NDC	Nationally Determined Contribution
NGGS	National Green Growth Strategy
NSL	Land and Water Division (FAO)

OCB	Office of Climate Change, Biodiversity and Environment (FAO)
PM	particulate matter
PPD	Plant Protection Department
R&D	research and development
SECO	Swiss State Secretariat for Economic Affairs
SPAM	Spatial Production Allocation Model
UNEP	United Nations Environment Programme
UNIDO	United Nations Industrial Development Organization
WHO	World Health Organization

Executive summary

This working paper provides an assessment of the current biochar sector in Viet Nam and introduces the AI4Biochar tool as an innovative, data-driven solution to support the sustainable development of this emerging market. Viet Nam's agricultural sector generates vast quantities of biomass residues, particularly from rice, coffee, and coconut production, most of which are currently underutilized or openly burned, contributing to significant greenhouse gas (GHG) and air pollutant emissions. Biochar offers a promising alternative, transforming agricultural waste into a valuable product that can enhance soil fertility, reduce input needs, sequester carbon, and supports circular economy principles.

The report outlines the enabling policy landscape, institutional arrangements, and current initiatives aimed at promoting biochar production and use. It identifies how various government ministries can collaborate to foster a functioning biochar market. Financial incentives, technical standards, public awareness, and inter-ministerial coordination are among the key levers discussed to unlock private and public investment.

A central feature of the report is the AI4Biochar tool, developed by FAO in collaboration with the University of Twente. Using machine learning and satellite imagery, the tool enables precise delineation of agricultural field boundaries and spatial analysis of feedstock availability, production planning, and environmental impacts. Applied in Tri Ton district in An Giang province, the tool estimated over 900 000 tonnes of rice residues annually (85 percent from straw and 15 percent from husks), highlighting significant feedstock potential for biochar production.

Environmental sustainability indicators, integrated within the AI4Biochar tool, underlined a strong transformative mitigation potential. Baseline GHG emissions from open burning of rice residues in the Tri Ton district were estimated at 89 000 tonnes of CO₂eq per year. Transitioning to biochar production could yield a tenfold reduction, with potential removals of over 860 000 tonnes of CO₂eq per year, averaging -18 tonnes of CO₂eq per year per hectare. In addition to GHGs, the AI4Biochar tool quantified substantial reductions in harmful non-GHG pollutants: carbon monoxide (CO) by 95 percent, nitrogen oxides (NO_x) by 86 percent, and complete elimination of sulphur oxides (SO_x) and particulate matter (PM). This is highly relevant for public health, as open biomass burning is a major contributor to respiratory illness, mortality, and environmental degradation across Viet Nam.

The results illustrate how the AI4Biochar tool can guide site selection for processing units, optimize transportation logistics, and support national strategies to reduce emissions, promote soil health, and improve rural livelihoods. It also demonstrates how centralized biochar processing, combined with decentralized residue collection, can offer scalable alternatives to open burning, easing the burden on farmers while adding value to waste streams.

The report concludes with strategic recommendations to the Ministry of Agriculture and Environment (MAE) and the Government of Viet Nam, including the development of a national biochar strategy, targeted financial instruments, certification schemes, and cross-sectoral

partnerships. It underscores the importance of aligning policies, mobilizing investments and leveraging technologies, such as AI4Biochar, to scale up sustainable biochar systems that contribute to climate resilience, air quality improvement, and inclusive green growth.

1. Background

In Viet Nam, a world leading producer of coffee, rice, and coconut, agricultural residues represent both a significant resource and a problem. Agricultural residues are often undervalued in Viet Nam, leading to practices like open-field burning or inefficient use as fuel. These practices contribute to air pollution with negative health and environmental consequences.

Biochar, one of the products of pyrolysis, could also be produced from agricultural residues, avoiding the release of harmful smoke. Biochar is a valuable product used as a soil amendment, increasing soil fertility while sequestering carbon, as well as for several other purposes.

The mitigation potential of biochar is well documented and increasingly recognized by the international scientific community, including the IPCC Sixth Assessment Cycle, which estimates that it could contribute up to 2.6 Gt CO₂eq per year in global carbon removals. This is largely due to its high content of recalcitrant carbon, a stable form of organic carbon that can persist in soils for centuries, making biochar one of the most durable carbon sequestration solutions currently available. However, its performance depends on a range of variables, including: (i) the type of feedstock used, (ii) production conditions such as temperature, pressure, and processing duration, (iii) soil type and agro-climatic conditions, and (iv) economic and logistical considerations, such as transportation needs due to its low bulk density.

Globally, the biochar market has been experiencing steady growth, driven by increasing interest in sustainable agriculture, carbon sequestration, and climate-smart practices. In regions such as North America and Europe, demand is fueled by supportive policy environments, carbon markets, and growing awareness of soil degradation and the need for regenerative practices. In Asia, countries like China and India have begun to invest significantly in biochar technologies, integrating them into large-scale agricultural and environmental programmes.

Despite this momentum, the Southeast Asian region, including Viet Nam, lags behind in market development. Among the constraints is insufficient information to support cost-benefit analyses to guide its future development. Detailed geospatial data is crucial for planning the optimal location of biochar processing units, considering factors such as proximity to agricultural producers with available biomass residues and prospective consumer locations.

About this report

This report, prepared by FAO, aims to outline the tools, framework and strategies necessary to promote the biochar industry within the country, focusing on how to stimulate investments and ensure sustainable growth in the sector. One key tool to support decisions is the AI4Biochar tool, which has been applied to Viet Nam as a proof of concept in 2024, and which is presented hereby.

With Viet Nam's growing agricultural industry generating large amounts of biomass residues, such as rice husk and straw, cassava peels, coconut residues, coffee husk, and sugarcane bagasse, there is considerable untapped potential for converting these residues into valuable biochar products, while improving soil health, sequestering carbon, and reducing greenhouse gas emissions. This would align with Viet Nam's broader climate change and sustainable agriculture goals illustrated in chapter II.

The report explores the current state of the biochar market in Viet Nam, which remains underdeveloped despite its significant potential. The report also emphasizes the need for a

comprehensive policy framework that can incentivize both public and private sector investments, as well as enhance capacity building for stakeholders involved in biochar production and application.

One of the key aspects of the report is an overview of mechanisms to support biochar investments, including financial incentives such as subsidies, concessional financing, and tax exemptions for businesses, which could be informed by tools such as the above-mentioned AI4Biochar tool.

Additionally, the report stresses the importance of creating a conducive regulatory environment and offering technical support to help farmers and producers adopt biochar technologies.

2. Overview of the biochar sector in Viet Nam

2.1. Production and use of biochar

Viet Nam possesses significant biomass resources due to its strong agricultural base. These resources represent a substantial opportunity for sustainable development, particularly in bioenergy and biochar production. However, the underutilization of biomass residues remains a pressing challenge, resulting in economic and environmental inefficiencies.

Annually, Viet Nam generates over 156.8 million tonnes of agricultural residues coming from a variety of sources (Le Hoàng Anh, 2024), reflecting the country's diverse agricultural production, ranking among the top countries in Southeast Asia in terms of biomass potential.

While biochar production is still relatively small-scale in Viet Nam, it is most prominent in regions where significant agricultural residues are produced, including the Mekong Delta, Red River Delta, Central Highlands, and Central Coast regions.

The Mekong Delta, located in southern Viet Nam, is one of the largest rice-producing regions in the country, generating substantial amounts of rice husks, straw, and other agricultural residues. This region has become a key region for small-scale biochar production, especially by rice farmers who use biochar to enhance soil quality, improve water retention, and reduce the reliance on chemical fertilizers.

Another key region for biochar production is the Red River Delta in northern Viet Nam, a major rice-producing area where large quantities of rice husks and other organic residues are available. In addition to rice, the Red River Delta also generates agricultural residues from crops such as maize and vegetables. The region is beginning to explore biochar production for use in sustainable farming practices.

The Central Highlands, known for its production of cash crops like coffee and cassava, also generate significant organic waste, such as coffee husks and cassava peels. Although biochar production in this region is not yet widespread, the agricultural residues offer potential for biochar conversion to improve soil and waste management.

Table 1. Annual amount of agricultural residues

#	Type of agricultural residue	Annual amount (approximate) (million tonnes)
1	Rice husks	9
	Rice straw	50
2	Corn stalks and cobs	10–12
3	Sugarcane bagasse	5–7
4	Coffee husks	1.5–2
5	Coconut residues	1–1.5

Source: Le Hoang Anh. 2024. Policy Review and Recommendations to Promote Biochar Production and Use in Vietnam.

In the North Central and Central Coast regions, agricultural residues from crops such as sugarcane, maize, and rice are abundant, though much of this biomass is often underutilized or burned, causing pollution. These areas have also begun exploring the production of biochar from sugarcane bagasse and rice straw as a mean to reduce waste and improve soil health.

In urban areas like Hanoi, Ho Chi Minh City, and Da Nang, there is potential for biochar production from organic waste, such as food scraps and garden waste, along with urban agricultural residues. In these cities, biochar is being explored as a waste management solution, for urban farming, and for its role in carbon sequestration.

According to Le Hoang Anh (2024), production of biochar can be found in the following provinces:

- Tuyen Quang, Yen Bai, Thai Nguyen and Lao Cai provinces use agriculture residues to make charcoal for ornamental flowers and plants and as boiler fuel;
- Hanoi, Tra Vinh, and Can Tho provinces use rice husk as fuel to dry agricultural products, the amount of biochar by-products produced to sell to farmers to fertilize fields;
- Dak Lak uses rice husks, coffee to dry coffee, biochar by-products are used to fertilize coffee trees;
- Son La makes use of the cob as biochar. One tonne of corn cobs can produce 3 tonnes of biochar, and the purchasing price of corn cobs is 1 100 VND/kg (USD 0.047), while the market price of biochar from corn cobs is 11 000 VND/kg (USD 0.47) (Moc Chau Xanh Company, 2019).

Biochar producing technology

Biochar production in Viet Nam relies on a range of technologies, varying from traditional methods to more advanced systems. These technologies are largely defined by the level of investment, production scale, and desired applications of biochar. The production process typically involves pyrolysis, a thermal decomposition of organic material in a low-oxygen environment, which converts biomass residues into biochar, along with gases and liquids. The technologies used can significantly influence the efficiency, yield, and quality of the biochar produced.

In many rural areas of Viet Nam, biochar is produced using traditional methods, such as earth kilns or simple open-pit pyrolysis systems. These low-cost technologies are accessible to small-scale farmers and local producers but often result in inefficient biomass conversion and low-quality biochar. The process is labour-intensive and can lead to significant emissions of harmful gases, making it less environmentally friendly. Despite these limitations, traditional methods are still widely used due to their low upfront costs and simplicity.

In recent years, improved kiln technologies have been introduced in Viet Nam to enhance the efficiency and environmental performance of biochar production. These include fixed-drum kilns and modified earth kilns, which allow for better control of the pyrolysis process. Improved kilns are more efficient at retaining carbon and reducing smoke emissions compared to traditional methods. They also produce higher-quality biochar with more consistent properties, making it more suitable for agricultural applications.

For larger-scale production, modern pyrolysis reactors are being introduced, primarily in pilot projects or by private companies. These systems, such as fixed-bed or rotary kilns, use advanced technology to optimize the pyrolysis process, resulting in higher yields of biochar and co-products like syngas and bio-oil. Some reactors are equipped with automated controls, enabling

precise temperature regulation and improved energy efficiency. These technologies are particularly promising for large-scale biochar production, although they require significant capital investment and technical expertise.

Some biochar production systems in Viet Nam are being integrated with renewable energy generation. These systems capture the gases and bio-oil produced during pyrolysis and use them as an energy source for heating or electricity generation. By co-producing energy and biochar, these systems enhance the economic viability of biochar production and contribute to a circular economy. However, such integrated systems are still in their infancy in Viet Nam and are typically part of research initiatives or pilot projects.

Despite these advancements, several challenges hinder the adoption of advanced biochar production technologies in Viet Nam. The high cost of modern pyrolysis systems and the lack of financial incentives make it difficult for small producers to transition from traditional methods. Additionally, limited technical expertise and inadequate infrastructure pose barriers to scaling up biochar production using advanced technologies.

Biochar use in Viet Nam

The overall market scale of biochar products is still limited compared to the scale of charcoal products (i.e. activated carbon, and biomass charcoal). According to Le Hoang Anh (2024), the production scale ratio is 16.3 percent, the market scale ratio is 5.2 percent, and the prices of biochar products vary significantly, ranging from 500 VND/kg to 12 000 VND/kg. The market scale mentioned above is determined based on the total market supply of biochar.

The distribution of biochar in Viet Nam is currently limited and fragmented, reflecting the small-scale nature of its production and the early stage of market development. Biochar distribution is primarily focused on meeting local demand, particularly in agricultural areas, with limited penetration into larger commercial or industrial markets. The distribution channels and practices vary based on the scale of production, target markets, and the level of awareness about biochar's benefits.

Most biochar is distributed directly by small-scale producers, including farmers and local entrepreneurs. These producers often sell biochar to neighboring farmers or use it for their own agricultural activities. The lack of intermediaries in these transactions simplifies the distribution process but limits the market reach to nearby communities.

In some regions, agricultural cooperatives play a role in distributing biochar. Cooperatives often purchase biochar in bulk from producers and distribute it among their members for use in farming activities. This model helps to streamline distribution within farming communities, especially in areas where cooperatives are active and well-organized.

Table 2. Market scale of charcoal, activated carbon, and biochar nationwide

#	Types of coal	Output (tonnes/year)	Average price (thousand VND/tonnes)	Scale (billion VND)
1	Charcoal	669 856	14 500	9 713
2	Activated carbon	96 600	128 125	12 377
3	Biochar	149 568		1 202

Source: Oxfam. 2021. International and Domestic Market Research Report for Biochar Products.

Small quantities of biochar are sold in local markets or through retail outlets that specialize in agricultural inputs, such as fertilizers and soil amendments. In addition to rice, the Red River Delta also generates agricultural residues from crops such as maize and vegetables. Retail distribution is more common in areas where biochar's agricultural benefits are better understood, such as regions with intensive rice cultivation.

Biochar applications

Biochar has a wide range of applications across agriculture, waste management, water treatment, energy production, and construction, making it a versatile solution for environmental and economic challenges. By addressing soil degradation, reducing emissions, and promoting resource efficiency, biochar can play a pivotal role in Viet Nam's sustainable development, climate resilience, and circular economy goals.

In agriculture, biochar is widely used as a soil amendment to enhance soil fertility, improve water retention, and boost microbial activity, particularly in degraded or nutrient-poor soils. By retaining nutrients such as nitrogen and phosphorus, biochar reduces the need for chemical fertilizers while minimizing nutrient leaching. It also contributes to carbon sequestration by storing carbon in the soil for hundreds to thousands of years. Additionally, in rice paddies, biochar has been shown to mitigate methane emissions by altering soil microbial processes, further supporting Viet Nam's efforts to reduce agricultural greenhouse gas emissions.

Biochar also plays an important role in waste management by converting agricultural residues, organic municipal waste, and animal manure into valuable resources, reducing air pollution caused by open burning and minimizing waste sent to landfills. As an effective tool for water and air filtration, biochar can remove pollutants such as heavy metals, pesticides, and organic contaminants from water, as well as absorb airborne pollutants and control odors in livestock operations and industrial processes. It can also be incorporated into storm water management systems to improve urban water quality.

In livestock farming, biochar is increasingly used as a feed additive to improve digestion, reduce methane emissions from ruminants, and enhance overall livestock health. Additionally, it can serve as bedding material to absorb moisture, reduce ammonia emissions, and control odors in animal housing systems. In the renewable energy sector, biochar production through pyrolysis generates useful byproducts such as syngas and bio-oil, which can be captured for clean energy production, reducing reliance on traditional fossil fuels. Biochar itself can also be used as a clean fuel alternative to firewood and charcoal, helping reduce deforestation and indoor air pollution in rural areas.

The construction industry also benefits from biochar, as it can be incorporated into building materials such as concrete and asphalt to improve strength, insulation, and weight reduction. Additionally, its use in construction supports carbon-negative practices by offsetting emissions. Biochar is further applied in environmental remediation, where it helps rehabilitate contaminated soils, adsorb heavy metals, and restore degraded land, such as mining sites.

Industrially, biochar shows promise in emerging applications, including its role in battery technology as a material for electrodes and in chemical processes as a catalyst support. These advancements highlight its growing potential as a sustainable industrial resource.

2.2. Legal and policy frameworks related to the production and use of biochar

The increasing emphasis on circular economy principles, sustainable agriculture, and environmental protection in recent years has led to greater attention being paid to the utilization of agricultural by-products in Viet Nam.

Below are some legal regulations and policies related to the use of agricultural by-products including for biochar:

- Resolution No. 57-NQ/TW of the Politburo (2024): on breakthroughs in science, technology, innovation and national digital transformation.
- Law on Environmental Protection (2020): Agricultural by-products are considered a recycled and reusable resource that needs to be managed to ensure that they do not cause waste and environmental pollution. The law requires agricultural production and processing facilities to have measures to collect, recycle or treat by-products to ensure that they do not cause environmental pollution. Encourage the recycling and reuse of waste, including agricultural by-products in the production of renewable energy, organic fertilizers, and other value-added products.
- Law on crop production (2018): Encourage the use of by-products from crops as organic fertilizers, animal feed, or raw materials for the production of other agricultural products and renewable energy. The Government supports organizations and individuals in researching and applying technology to treat agricultural by-products.
- Law on Livestock (2018): Regulates the utilization of agricultural by-products (straw, corn stalks, bagasse, etc.) as animal feed. Encourages the production and use of organic fertilizers from livestock waste and agricultural by-products.
- Circular 09/2020/TT-BNNPTNT: Regulations on livestock waste management, requiring livestock facilities to apply measures to utilize waste and by-products as fertilizers or raw materials for renewable energy production.
- Circular 08/2022/TT-BTNMT: Technical guidance and requirements for agricultural waste recycling projects.
- Decision 1719/QĐ-TTg (2021): Approves the organic agriculture development programme for the 2021-2030 period, encouraging the use of agricultural by-products as organic fertilizers and biological products.
- Decision 873/QĐ-BNN-KHCN (2021): Orientation for research and development of agricultural by-product treatment technology, support for projects to develop recycling and reuse of by-product technology.
- National Action Plan on Food System Transformation: This plan, approved in 2023, emphasizes the need for mechanisms to promote PPPs in infrastructure investment for food systems, including transportation, logistics, cold chain, and high technology.

2.3. Existing initiatives and projects

In the recent years, Viet Nam's biochar sector has witnessed the implementation of numerous initiatives and projects, led by government agencies, research institutions, international organizations, and private enterprises. These efforts aim to scale biochar production, promote its adoption, and integrate it into sustainable agricultural and environmental strategies.

The Vietnamese government, through the Ministry of Agriculture and Rural Development (currently Ministry of Agriculture and Environment), has integrated biochar into national programmes promoting sustainable agriculture. Initiatives focus on using biochar as a soil amendment to enhance soil health, reduce dependency on chemical fertilizers, and improve crop yields. Biochar application in rice paddies has been prioritized as a key strategy to mitigate methane emissions, aligning with Viet Nam's greenhouse gas (GHG) reduction goals.

Several research institutions and universities have launched pilot projects to demonstrate the benefits of biochar and advance technological innovation. The Vietnam Academy of Agricultural Sciences (VAAS) has conducted field trials on biochar's role in enhancing crop productivity and soil fertility. Institutions like Can Tho University and Hanoi University of Science and Technology are focusing on efficient biomass conversion technologies, studying the impacts of biochar on agricultural systems, and promoting its use in the Mekong Delta, where agricultural residue production is abundant.

International development organizations have played a significant role in supporting biochar-related programmes. The United Nations Development Programme (UNDP) and the Global Environment Facility (GEF) fund projects to reduce emissions by converting agricultural residues into biochar instead of open burning. Organizations like SNV Netherlands Development Organization emphasize biochar's role in waste-to-resource initiatives and renewable energy programmes. UNIDO has successfully transferred a pyrolysis technology from Switzerland to Viet Nam, leading to the manufacturing of small-scale biochar production systems (pyrolizers) from agroresidues in Viet Nam. These systems are now being exported also to other countries.

The private sector has increasingly contributed to biochar production and technology development. Small and medium enterprises (SMEs) are investing in pyrolysis technology to produce biochar from abundant agricultural residues, such as rice husks, straw, and sugarcane bagasse. Startups have introduced portable and decentralized pyrolysis units, enabling rural communities to convert waste biomass into biochar on-site. These initiatives improve resource efficiency while creating additional economic opportunities for farmers and entrepreneurs.

Climate and carbon market initiatives are also emerging as a mechanism to scale biochar production. Projects funded by development banks and impact investors are quantifying the carbon sequestration potential of biochar to enable participation in carbon credit markets. Revenue from carbon credits provides financial incentives for farmers and businesses to adopt biochar solutions. Additionally, Viet Nam is exploring ways to integrate biochar into its Nationally Determined Contributions (NDCs) under the Paris Agreement, focusing on agriculture and land use sectors.

At the community level, NGOs and local organizations are actively promoting biochar adoption. Organizations such as GreenID Viet Nam and the Viet Nam Farmers' Union conduct awareness campaigns and training programmes, equipping farmers with the knowledge and tools to produce and use biochar effectively. These initiatives emphasize biochar's role in reducing biomass burning, improving rural livelihoods, and fostering circular economy practices.

One of the most prominent biochar projects is the Biochar for Sustainable Soils (B4SS).¹ The project, which involves both local and international partners, aims to showcase how biochar can enhance soil fertility, improve crop yields, and contribute to more sustainable agricultural practices. It combines scientific research with practical field trials to illustrate biochar's potential in addressing soil degradation, a major issue in many parts of Viet Nam due to intensive farming and soil erosion. The B4SS Project aims to educate farmers on the benefits of biochar, focusing on improving soil structure and nutrient retention, and promote adoption of sustainable

¹ For more information visit: <https://b4ss.tnus.edu.vn/>

agriculture practices. The project involves conducting field trials in various agricultural regions, providing farmers with hands-on experience in using biochar for soil enhancement, and demonstrating its ability to increase productivity, particularly in areas with poor or degraded soils. Workshops, training programmes, and knowledge-sharing activities are central to the initiative, ensuring that farmers, agricultural professionals, and local stakeholders understand how to incorporate biochar into their practices effectively.

*The Rice Husk to Premium Biochar Project in the Mekong Delta*² is a collaborative initiative designed to address environmental, agricultural, and economic challenges associated with rice husk waste in Viet Nam. The project involves partnerships between Vietnamese and Australian universities, local biochar producers, and the Australian Department of Foreign Affairs and Trade. The project utilizes advanced pyrolysis technology to convert rice husk residues into high-quality biochar, addressing waste management and promoting sustainable agriculture. By transforming rice husks into biochar, the project not only reduces greenhouse gas emissions but also promotes sustainable waste management. The biochar produced enhances soil health by increasing water retention, improving nutrient availability, and reducing issues like soil acidification and nitrate leaching. This results in better crop yields and supports more resilient farming practices, which are essential in one of Viet Nam's most critical rice-growing regions. By creating a market for rice husks, farmers gain additional income from selling this agricultural byproduct. The premium biochar is sold as a valuable product, further generating economic opportunities for local producers and communities.

The "*Biochar for Carbon Removal and Improved Livelihoods in Viet Nam*" project³ is a collaboration involving Biocare Projects, EnergyLink Services, the University of Adelaide, Ho Chi Minh City University of Technology, and local partners in the Mekong Delta. Supported by the Australian Department of Foreign Affairs and Trade, the initiative focuses on converting waste rice husks into high-quality biochar using advanced pyrolysis technology to:

- Reducing methane and CO₂ emissions from waste biomass burning.
- Enhancing soil fertility and water retention through biochar application.
- Generating carbon credits, creating an additional income stream for communities.

With a goal to sequester approximately 15 000 tonnes of CO₂ annually, the project not only mitigates climate change but also improves livelihoods by promoting sustainable practices and supporting local farmers.

The *BiGchar 2200 Biochar Production Technology Installation* project demonstrates the practical application of advanced biochar production technology in Viet Nam. Installed at an EcoFarm facility near Ho Chi Minh City in 2014, the BiGchar 2200 model biochar production unit is designed to efficiently convert agricultural residues, such as corn and rice byproducts, into high-quality biochar through pyrolysis. The technology allows for the sustainable use of biomass waste while producing valuable biochar that can be utilized in agriculture to improve soil health and reduce carbon emissions. As the agricultural residues undergo pyrolysis, the system generates bioenergy that can be used to power the facility, thus reducing reliance on external energy sources.

² For more information visit: [Vietnam BPP](https://www.biocareprojects.com/post/vietnam-bpp) (<https://www.biocareprojects.com/post/vietnam-bpp>)

³ For more information visit: <https://thebpp.com.au/partnership/biochar-carbon-removal-improved-livelihoods-vietnam/>

3. Decision-making tools and the AI4Biochar tool

3.1. Description of the AI4Biochar tool

Establishing efficient supply chains and logistics networks is essential for expanding the reach of biochar and making it accessible to a broader range of users. Comprehensive information on the availability, quality, and current uses of agricultural residues is crucial for optimizing and enhancing the efficiency of the biochar supply chain in Viet Nam.

The FAO AI4Biochar tool can be used to generate detailed, spatially explicit information and sustainability indicators relevant to the biochar sector in the country. AI4Biochar is a customized application of an advanced prototype that leverages artificial intelligence (AI) and machine learning techniques to delineate agricultural field boundaries using freely available satellite imagery. Satellite imagery is used as input, together with crop production maps, to delineate field boundaries. For each field, the amount of residues that can be sustainably removed are calculated, together with the biochar needs to maintain soil carbon and a number of sustainability indicators. This innovative approach not only facilitates better resource management but also aids in identifying potential sites for biochar production and provides an indication of the impacts on selected sustainability indicators of such investments.

This chapter provides background information on the original AI prototype and presents a detailed overview of the sustainability indicators and set of information relevant to the development of the biochar sector. The chapter then presents all the technical steps involved in the customized application of the prototype to a study area of Viet Nam, including the results from the integration of a set of selected sustainability indicators.

Finally, the chapter also highlights other tools currently employed in Viet Nam to bolster the growth and sustainability of the biochar sector.

3.2. An AI prototype to delineate crop field boundaries

Accurate delineation of crop field boundaries is essential for optimizing biochar production and its associated sustainability assessments. Precise boundaries enable reliable estimates of available agricultural residues, strategic placement of biochar production units, and accurate evaluation of economic, environmental, and social sustainability indicators at detailed spatial scales.

The AI4Biochar tool utilizes an advanced machine-learning prototype designed to automate the extraction of crop field boundaries from freely available satellite imagery.⁴ This prototype, initially developed by FAO in collaboration with the University of Twente, addresses the labour-intensive process of manual digitization, particularly challenging in regions like Viet Nam, characterized by numerous smallholder plots, often smaller than 1 hectare. Although initially tested on rice paddy fields, the prototype is versatile and adaptable across various crop types and agricultural systems.

⁴ The AI4Biochar project utilizes a modified U-Net deep learning architecture called Satellite U-Net, specifically implemented using TensorFlow. This convolutional neural network (CNN)-based segmentation model is designed to automatically delineate agricultural field boundaries from satellite imagery. It processes Sentinel-2 imagery by first segmenting images into binary raster outputs indicating field boundaries, which are subsequently refined through morphological segmentation techniques to enhance boundary accuracy and vectorized into spatial polygons for further analysis.

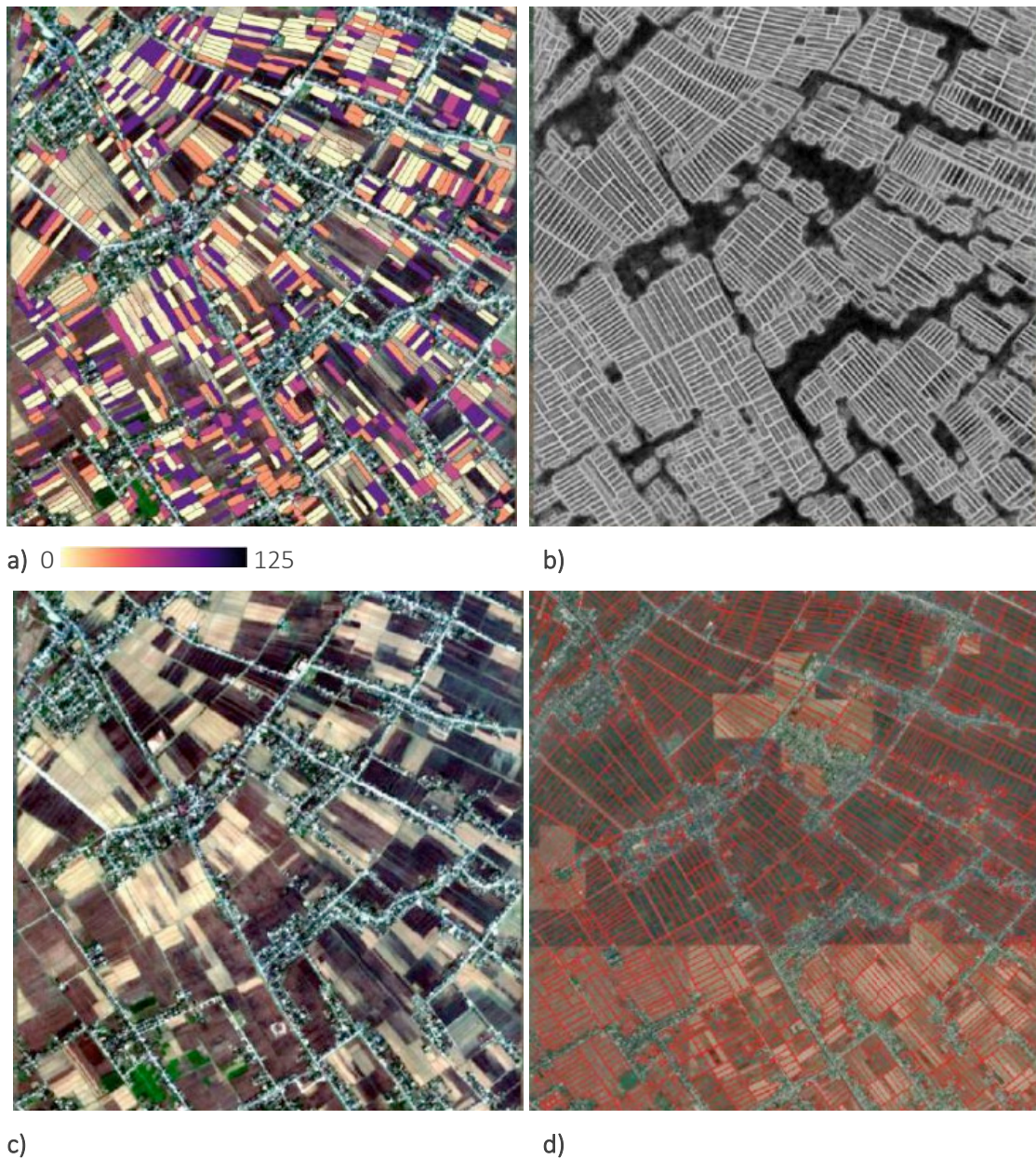
The output of the prototype is a spatial vector of agricultural field boundaries.⁵ The resulting layer can be subsequently populated with information generated from crop type mapping activities, but also with existing crop type maps.

In a previous phase of the development, results were tested against a reference dataset. The dataset comprises 439 001 field polygons divided into 62 nonoverlapping tiles of approximately 5×5 km distributed across Viet Nam and Cambodia. The field polygons were meticulously digitized using Sentinel 2 and VHR Google Map (GM) images, following a rigorous multistep quality control procedure and topological consistency checks (Persello *et al.*, 2023). At the date of its release, AI4SmallFarms represented the first large-scale open dataset available to the public for smallholder farming in Southeast Asia.

Figure 1 illustrates some results of the U-Net model against the reference dataset, in both qualitative and quantitative terms. The crop boundary maps are presented by reporting the Polis values together with deep learning (U-Net) model output (boundary score), true colour composition of the Sentinel-2 monthly composite, and the reference crop field boundaries highlighted in red and overlaid on top of the Very High resolution (VHR) Google basemap images. The lower the Polis values (i.e. yellow and dark colours), the better the delineation of crop boundaries from a geometric point of view. From the results obtained, most of the outlined crops have a good correspondence with the manually digitized reference polygon.

⁵ In more details, satellite imagery processing in the AI4Biochar project begins with acquiring Sentinel-2 images through Google Earth Engine (GEE), specifically selecting images with minimal cloud coverage during the dry months (January and February). These images are pre-processed by creating cloud-free monthly composites using a statistical method that aggregates pixel values by computing median values to effectively exclude clouds and shadows. The critical spectral bands—blue (B2), green (B3), red (B4), and near-infrared (B8)—are utilized due to their importance in distinguishing agricultural field boundaries. Following initial processing, the images are segmented using the Satellite U-Net deep learning model, resulting in binary rasters marking field boundaries. Finally, morphological segmentation and vectorization procedures refine these rasters into precise polygonal representations of agricultural fields, suitable for detailed spatial analysis.

Figure 1. Crop boundary delineation results obtained in Tile 30 (Viet Nam): (a) boundary predictions from the U-Net associated with the Polis values, (b) the deep learning model output (boundary score), (c) true color composition of the Sentinel-2 monthly composite, and (d) reference crop field boundaries highlighted in red and overlaid on top of VHR google images.



Source: Authors' own elaboration.

Table 3 provides a comprehensive overview of the quantitative results, namely precision, recall, F1-score, and polis metrics, for some of the reference tiles situated in Cambodia and Viet Nam. The results reveal that the delineation of crop boundaries demonstrates consistency and accuracy across both regions, regardless of the varying crop conditions observed in Cambodia and Viet Nam. This consistency suggests that the methodology employed for crop delineation is effective and reliable, demonstrating the potential for its applicability across diverse agricultural landscapes, including using Sentinel 2 imagery with limited spatial resolution (10 m).

Table 3. Field boundary prediction performances obtained on the test set in terms of Precision, Recall, F1-Score and Polis (m).

	Tile #	Precision	Recall	F1-score	Polis (m)
Cambodia	8	0.5	0.34	0.4	19.3
	12	0.55	0.39	0.46	17.1
	16	0.57	0.37	0.45	21.51
	21	0.43	0.34	0.38	23.85
	58	0.53	0.39	0.45	17.66
Viet Nam	26	0.45	0.41	0.43	33.42
	27	0.45	0.22	0.3	34.99
	30	0.59	0.43	0.5	29.86
	46	0.38	0.24	0.3	29.02
	56	0.35	0.21	0.26	39.91
Overall		0.48	0.33	0.39	26.66

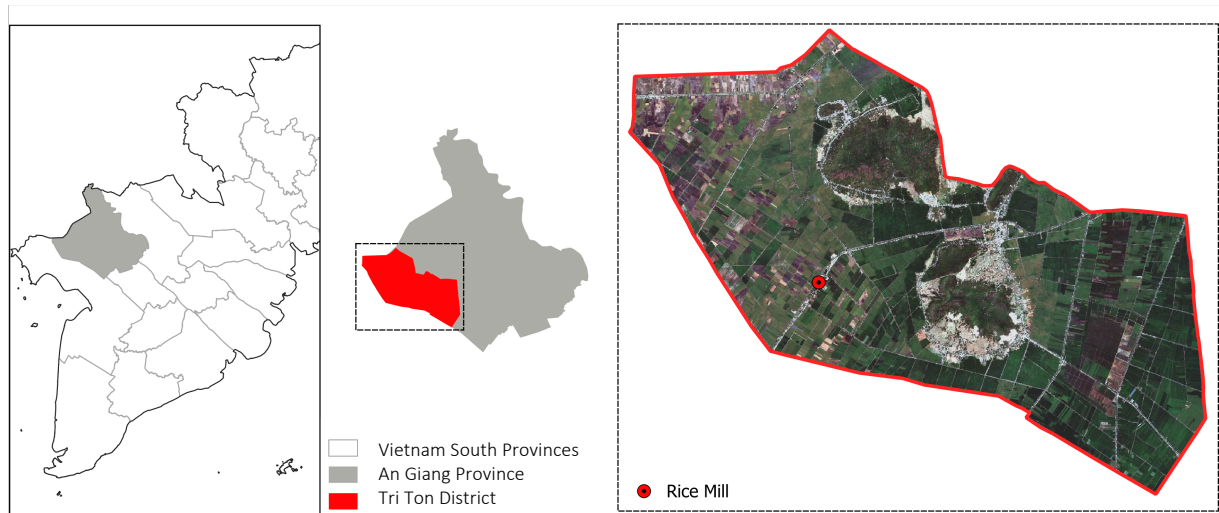
Note: The results are reported for selected tiles and across the whole test set, for Tile 30 in Figure 1.
Source: Authors' own elaboration.

The AI prototype code can run within a free processing platform such as Google Colab. A detailed guidelines of the architecture and steps needed to run the model is available in a detailed technical guideline, which can be requested from FAO.

3.3 Customization of the AI prototype for AI4Biochar and application to Viet Nam

As previously mentioned, the AI prototype is applicable to all crop types where field boundaries can be distinguished. FAO has tested its customization for three of the main crops in Viet Nam: rice, coffee and coconut. This section presents the results from the application of the prototype to the Tri Ton district, located in An Giang province, an area renowned for its rice production (Figure 2).

Figure 2. Location and relevant statistics of the Tri Ton district



Tri Ton	2020
District area (ha)	59 800
Rice Harvested area (ha)	118 007
Yield (tonne/ha)	5.75
Production (tonne)	679 044

Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.

Source: Authors' own elaboration. Statistical data are reproduced with permission of the Vietnamese Ministry of Agriculture and Environment.

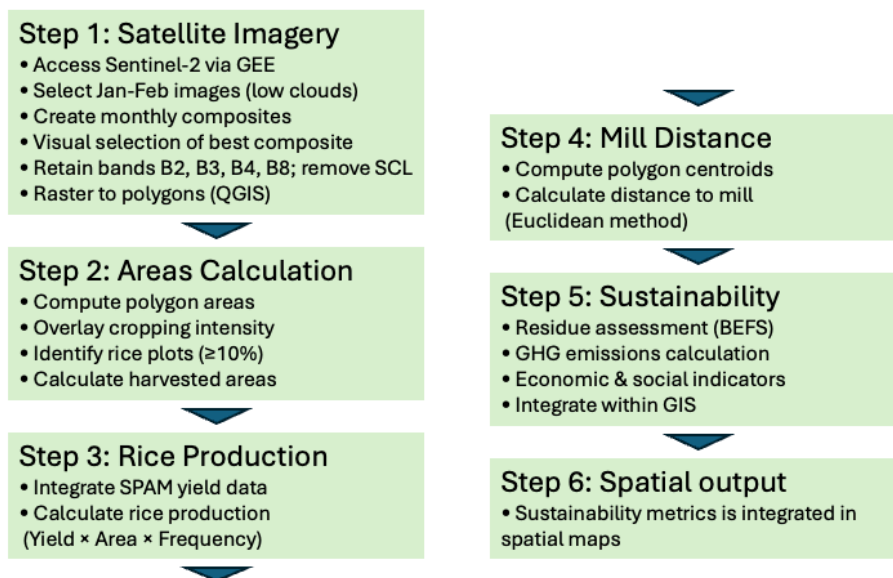
More development is however required to extend the good results yielded in Tri Ton, to coffee and coconut productions, namely due to the difficulty to identify the field boundaries for these permanent crops with comparable success.

Operational assumption

To streamline the AI prototype's technical customization for biochar production in rice fields, the analysis leveraged a strategic assumption: existing rice mill locations were treated as priority zones for pyrolysis unit deployment. Several reasons support this setup. Firstly, the availability of rice husks at rice mills. Rice husks are secondary crop residues which can provide readily available biomass for the pyrolysis units. Secondly, it is assumed that logistics and transportation arrangements are already in place, which can be adapted to support the production and distribution of biochar. Thirdly, it is expected that rice mills already have storage facilities which can be used by the biochar supply chain with reduced costs.

Technical steps are presented in the Figure 3 and discussed below.

Figure 3. Technical steps for the application of the AI4Biochar tool



Source: Authors' own elaboration.

Step 1. Preparation of the satellite imagery

A preliminary phase of the implementation of the prototype involves traditional geospatial analysis to identify and prepare the Sentinel 2 image in a format suitable to run the prototype. These pre-processing activities are performed in the cloud-based platform Google Earth Engine (GEE). Because of the heavy cloud coverage typically present in the considered study area, the atmospherically corrected Sentinel 2 images are preprocessed to generate monthly composites almost free of clouds using a standard statistics-based approach. This approach aggregates all the Sentinel 2 images acquired within a month into a composite by calculating the median pixel value, excluding the pixels that are affected by clouds or shadows. In this customization, we focused on the least cloudy months of the dry season, i.e. mainly January and February, by selecting only the images having cloud cover < 40 percent. For each tile, the monthly composites obtained were visually inspected to select the least cloudy one. The blue (B2–490 nm), green (B3–560 nm), red (B4–665 nm), and near-infrared (B8–842 nm) bands are considered, since these are the most relevant spectral bands for crop boundary delineation and the ones acquired at the highest spatial resolution, i.e. 10 m. On top of the four desired bands, the ‘SCL’ band for cloud masking is also included in each image downloaded from GEE, but this band is subsequently removed before running the Python code. The 2021 February monthly composition performs better in predicting field boundaries than the annual composite and the composites of the other months. This can be attributed to the fact that bare soil in the winter season provides a more distinguishable view of the field boundaries than green ground covers. Images for the year 2021 were explored as the benchmarking dataset AI4SmallFarms is based on images of this year.

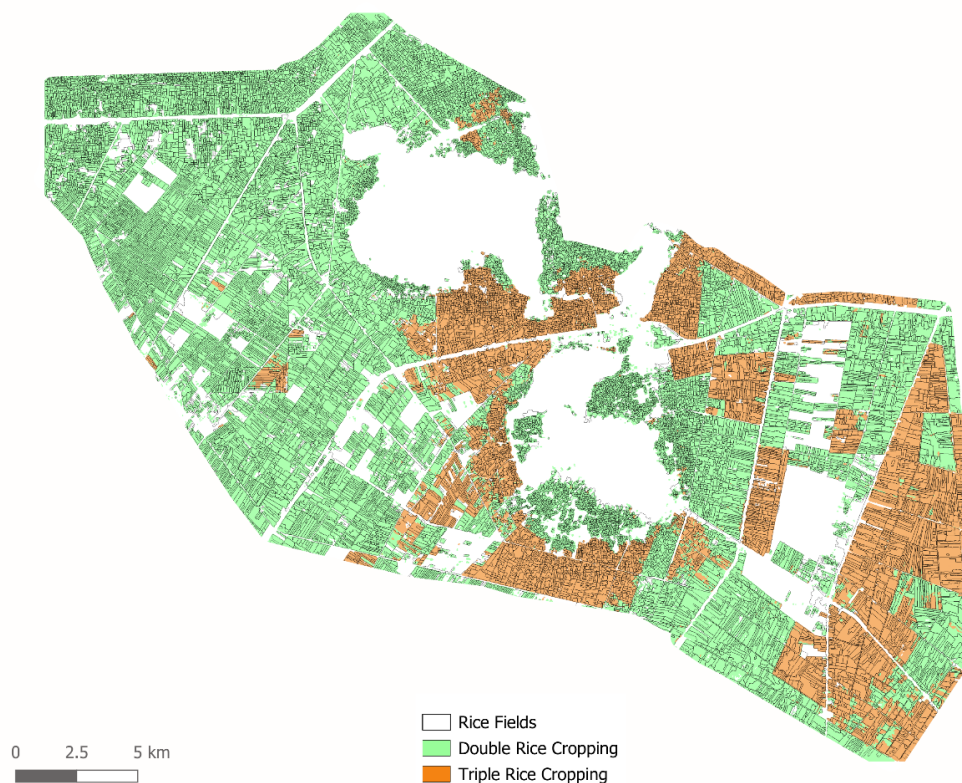
The final step of the AI prototype generates a raster image with pixels showing binary values, 1 for crop boundaries and 0 otherwise. A final post-processing step is required to convert these rasterized boundaries in closed vectorial polygons, producing in this way a spatial vector of closed polygons covering the entire image. This post-processing and subsequent GIS steps are all implemented in QGIS, a freely available GIS software with a large community of practice and wide capabilities including for processing of remote sensing images.

Step 2. Compute physical and harvested areas of rice per plot

The GIS software calculates the area of each plot within the vector of polygons. At this point of the analysis, the geospatial layer is crop-neutral as it delineates any agricultural field without discriminating them by the crop grown in the plot. In this implementation, and due to the lack of time for more specific rice mapping developments for this pilot application in Viet Nam, it was decided to rely on existing rice maps. We used the SEA-Rice-Ci10 dataset, a high-resolution (10 m) map of rice cropping intensity and harvested area (Ginting *et al.*, 2024). Similarly to the Sentinel 2 images used in the prototype and the benchmarking dataset, this dataset has 2021 as reference year and was produced from the satellites Sentinel 1 and Sentinel 2 imagery. The map includes information on the number of rice harvests, thus distinguishing between pixels with a single, two or up to three harvests within the year.

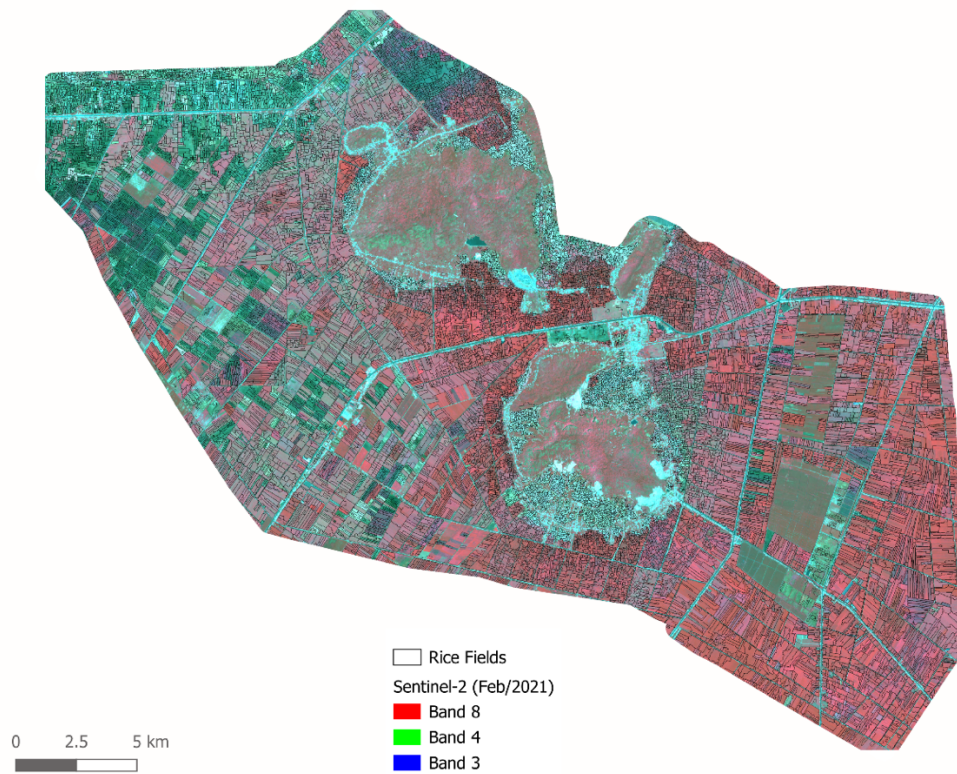
The SEA-Rice-Ci10 maps were overlaid with the layer of agricultural plots boundaries showing that the majority of plots in the Tri Ton district have high rice cropping intensity with 2 and even 3 harvests per year (Figure 4). Agricultural plots were selected on a minimum of 10 percent overlap with areas classified as rice in the SEA-Rice-Ci10 map. Results from this geospatial analysis measured a total of 28,102 rice plots in the district of Tri Ton with an average physical area of rice of 1.75 ha and a total harvested area of 94,187 ha. Nearly two thirds of the harvested area come from plots with double annual harvests and the remaining from triple harvests, indicating optimized land use. Dense clustering of multi-harvest plots suggests favorable irrigation/soil conditions in specific zones.

Figure 4. Overlay of the plot boundaries with a rice cropping intensity map, in the district of Tri Ton



Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.
Source: Authors' own elaboration.

Figure 5. Rice plots overlaid on a Sentinel-2 image from February 2021, used for plot boundary delineation, in the district of Tri Ton



Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.
Source: Authors' own elaboration.

Table 4. Rice plot statistics: number, average area, total area and harvested areas, in the district of Tri Ton

Number of plots	Average rice plot area	Total rice physical area	Total harvested area
30 446	1.7 ha	48 646 ha	94 187 ha

Source: Authors' own elaboration.

Step 3. Compute rice production for each plot

Rice production quantities represent a fundamental variable for the computation of most sustainability indicators described in Section 3.2. Production quantities can be calculated by multiplying the yield, expressed in quantity per unit of area (e.g. tonnes per hectare), by the area harvested. Official statistics indicate an average yield of 5.75 tonnes/ha for the district of Tri Ton. To increase the spatial variability and the granularity of the information, we opted to use an additional spatial dataset. The SPAM dataset (IFPRI, 2024), with reference year circa 2020, provides information at 10 km spatial resolution on the physical and harvested area, as well as yields of multiple crops, including rice. Rice yields in the Tri Ton district range between 5 and 9.5 tonnes/ha, with an average of 6.2 tonnes/ha for the selected rice plots, which closely aligns with the official statistics (Figure 6).

Figure 6. Rice plots overlaid on the SPAM rice yield map in the Tri Ton district



Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.
Source: Authors' own elaboration.

Based on the analysis above, the total yearly (circa 2020) production from all rice plots in the Tri Ton district was computed from Equation 1 as follows.

$$TriTon_{y-prod} = \sum((yield_{y-rplot} * (a_{rplot} * hrv_{y-r})))$$

where

$TriTon_{y-prod}$ is the total amount of rice produced yearly from the the district of Tri Ton (in kg)

$yield_{y-rplot}$ is the yield of rice in each plot, derived from the overlay of the AI vector of polygons with the SPAM dataset (in kg/ha)

a_{rplot} is the area of each plot where rice is grown, as computed from GIS functionalities (in ha)

hrv_{y-r} represent the number of times rice was harvested annually from each rice plot in the Tri Ton district (i.e. 1, 2 or 3)

Based on the new analysis, we could report here some statistics for the production and compare with the official statistics (Table 5). The geospatial analysis produced results that are generally comparable to official statistics. The spatial extent of the district was found to be virtually identical in both datasets. However, the analysis revealed lower estimates for both rice harvested areas and total production, showing differences of -20 percent and -16 percent, respectively.

In contrast, the average annual yield of rice in the district was found to be 9 percent higher in the AI/GIS analysis compared to official statistics. While there is insufficient information to determine whether the discrepancies in the geospatial analysis fall within the range of uncertainties of the official statistics, it is noteworthy that the overall comparability is commendable, especially considering that global datasets were utilized in this analysis.

Step 4. Compute the distance of each plot to the rice mill

Based on our operational assumption, the crop residues collected from each rice plot would be gathered and transported to a location in the proximity or coinciding with the position of existing rice mills. The distance of each plot from this 'optimal' location influences the transportation costs as well as the amount of greenhouse gas emissions associated with the fuel consumption. Hence, this distance represents another important variable that enters in the analysis and to derive several of the sustainability indicators. This variable is computed with traditional GIS techniques by first identifying the centroid of each rice plot and then computing the Euclidean distance from these centroids to the location of the rice mill identified in Tri Ton district.

Attempts have been made to compute actual distances by including the road network in the analysis. However, due to data and time constraints, it was preferred to limit the analysis to the simplified Euclidean distances, which represent a good proxy considering the limited extent of the study area. On average plots are located 12.5 km away from the rice mill, the minimum distance is 300 m and the maximum distance 27.5 km.

Table 5. Summary results from the geospatial analysis and comparison with official statistics (2020) in the Tri Ton district

	Official Statistics	AI/GIS	Difference
District area (ha)	59 800	59 450	-1%
Rice harvested area (ha)	118 007	94 187	-20%
Average yield (tonnes/ha)	5.7	6.2	9%
Production (tonnes)	679 044	570 594	-16%

Source: Authors' own elaboration.

Step 5. Compute and integrate sustainability indicators per plot

The biochar market is primarily driven by the promising benefits this product offers for agricultural production. Biochar is widely recognized for its ability to enhance soil quality, improve water retention, and reduce reliance on chemical fertilizers. Moreover, the development of a biochar supply chain is anticipated to generate significant socio-economic benefits, including job creation and increased income opportunities. These combined advantages make biochar an appealing solution for farmers looking to adopt sustainable and efficient agricultural practices.

Open burning of agricultural residues poses significant environmental challenges, increasing greenhouse gas (GHG) emissions and air pollution. Biochar offers a compelling alternative: when incorporated into soils, its organic carbon is sequestered for extended periods, acting as an effective carbon removal solution.

Accurate field boundary delineation is crucial for spatially explicit attribution of key features relevant to biochar production to each plot. These features are assessed using specific sustainability indicators (SIs) designed to capture the environmental, social, and economic benefits derived from biochar production and use.

The AI4Biochar tool leverages delineated plot boundaries and national rice production statistics to:

- a) Assess the sustainable agricultural residue production potential of rice plots in the case study area.
- b) Evaluate the sustainability impacts of converting these residues into biochar.

Specifically, assessment (A) was conducted using the Food and Agriculture Organization (FAO)'s Bioenergy and Food Security (BEFS) approach (FAO, 2014). Assessment (B), the sustainability impacts of biochar production, was conducted using a set of Sustainability Indicators (SIs) specifically developed for the project.

The BEFS approach is aimed to support countries create sustainable bioenergy policies that promote food and energy security while supporting agricultural and rural development. It provides tools and guidance for various stages of policy development, adaptable to a country's bioenergy progress and policy needs.

The AI4Biochar tool is based on the Agricultural Residues tool, and specifically the Crop Residues Module, of the FAO BEFS Rapid Appraisal (BEFS-RA)⁶ approach (Figure 7). The BEFS-RA was used to calculate crop residues production, disaggregated by type of residues (i.e. husks; straws). The BEFS-RA also computes the quantity of residues that should remain in the field to ensure soil functions even before biochar incorporation, thus impacting the sustainability of the whole rice value chain. This approach enables the estimation of the amount of feedstock to be used for biochar production while maximizing positive effects on biodiversity, soil structure and quality.

⁶ For more information, visit: [Rapid Appraisal | Energy | Food and Agriculture Organization of the United Nations](#)

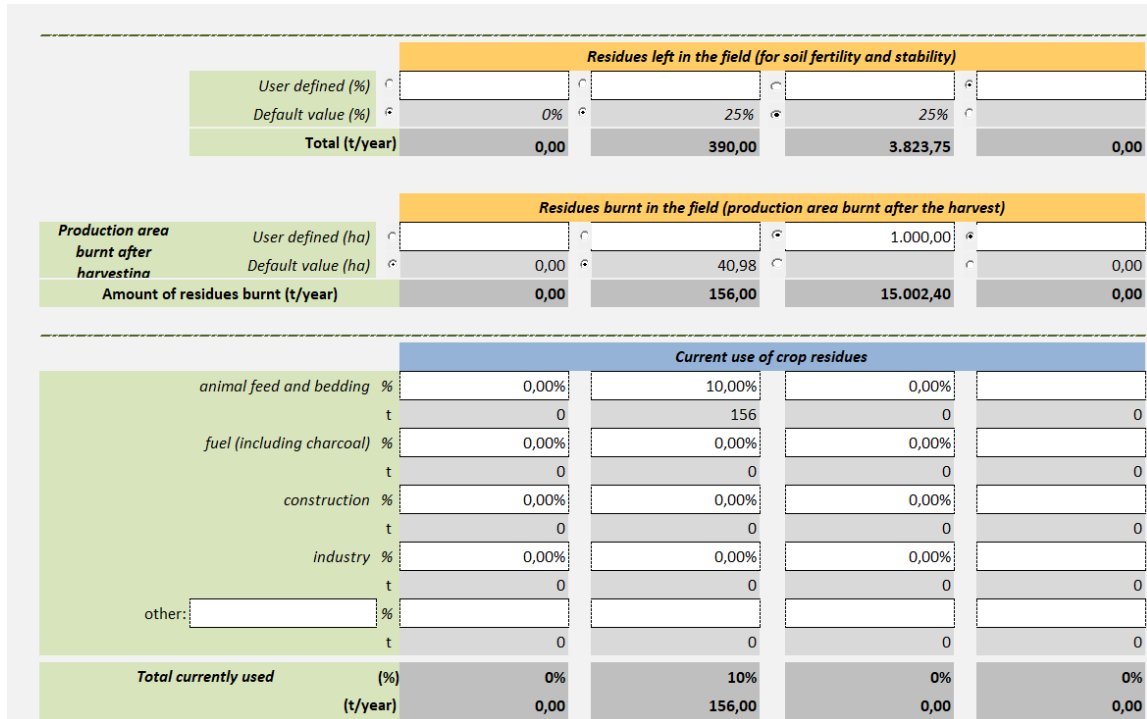
Figure 7. The BEFS-RA Crop Residue module allows to calculate residue production by crop residue type for several modeled crops, including coffee, rice and coconut.

CROP RESIDUES					
COUNTRY: Viet Nam		<< BACK Agricultural Residues		NEXT >> Results of the Agricultural	
BEFS Rapid Appraisal for	Province:	Enter data into white cells		Grey cells are calculated	
Select crop-residue type					
	Crop 1	Crop 2	Crop 3	Crop 4	
Crop	coffee	coconut	rice	Select a crop	
Residue	husk	shell	straw	#N/A	
Location of residue generation	processing plant	field - spread	field - spread	Select location	
Crop production					
Crop yield (t/ha)	2,41	9,76	5,64		
No. of harvests/year	1,0	1,0	2,0		
Annual production (t)	2.000	4.000	11.500		
Total production area (ha)	829,88	409,84	1.019,50	0,00	
10-years average annual production at country level (based on FAOSTAT 2010-2019)					
Parameter	Unit	Crop 1 coffee	Crop 2 coconut	Crop 3 rice	Crop 4 Select a crop
Crop	t/ha	2,41	9,76	5,64	-
Production	t/year	1.413.230	1.397.206	43.361.586	-

Source: Authors' own elaboration.

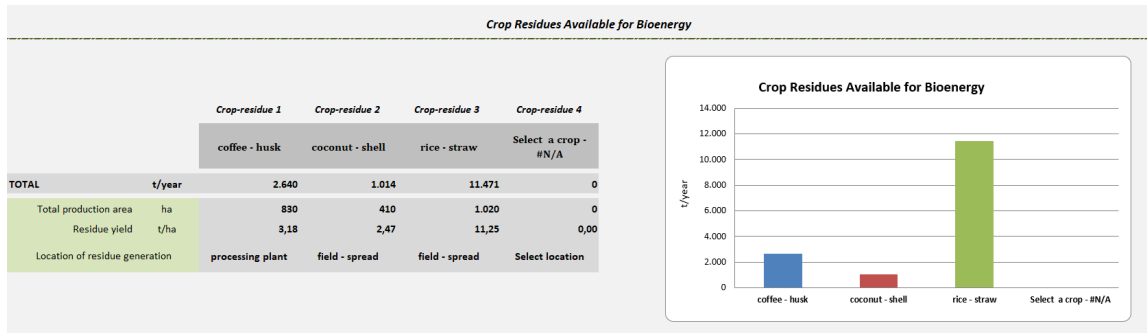
The tool is an Excel-based calculation sheet which includes sections for calculating crop production, residues generation, residues left in the field, and residues burned in the field, and finally a section that estimates residues potentially available for bioenergy (in this case, biochar). The system uses default values obtained from long-term time series, international datasets (e.g. FAOSTAT) and specific literature, but can be overridden by using primary data or user-defined values, where these are available. The key inputs required are the country where the project takes place, crop type involved (in this case, rice), the specific residue types considered (such as rice straw and rice husk), crop yield, number of harvests per year, annual crop production, and the residue-to-crop ratio. The tool makes use of information from the AI application (e.g. crop boundaries used to determine actual plot size), national statistics (on yield and total crop production) and default values from the BEFS RA (crop-to-residue production ratio, and sustainable residue removal rates).

Figure 8. The BEFS-RA tool can display parameters that define the sustainable availability of residues for biochar production. The model considers competing uses of residues to determine the sustainable removal rate for each crop residue type.



Source: Authors' own elaboration.

Figure 9. The results of the BEFS-RA Crop Residue Module are presented in numerical and graphical form, with a table and a histogram graphic respectively.



Source: Authors' own elaboration.

The Crop Residue Module computes the amount of feedstock that can be sustainably used for biochar production. Biochar production amounts have been calculated in a dedicated calculator, also Excel-based (Figure 10) which returns values for biochar production and related sustainability indicators (SIs) values. The SIs have been specifically designed for this project and are based on the [Global Bioenergy Partnership \(GBEP\) Sustainability Indicators for Bioenergy](#). The GBEP 24 indicators assess the sustainability of all bioenergy forms and they aim to support policymakers and stakeholders evaluating bioenergy pathways against traditional bioenergy or fossil fuels.

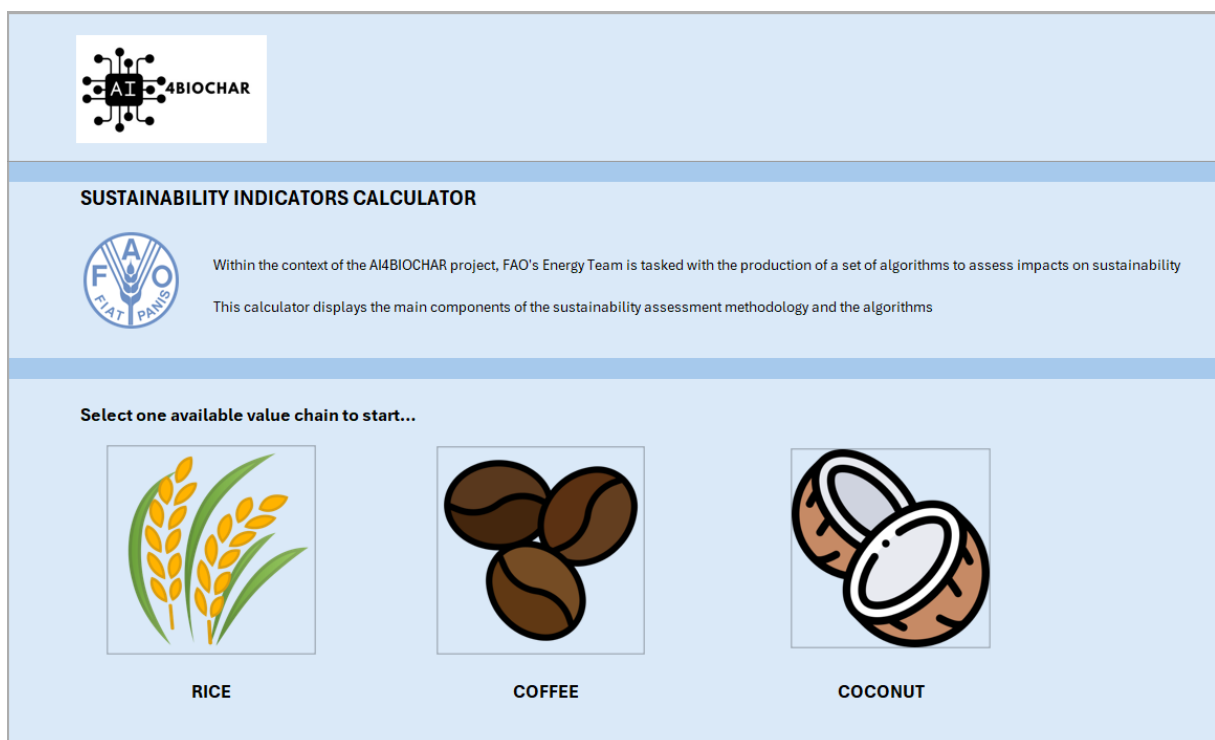
Specifically, 4 key indicators of sustainability were selected for the AI4Biochar tool: GHG and non-GHG emissions, employment, and income generation (Table 6).

The AI4Biochar sustainability performance assessment compares two distinct scenarios:

- **Baseline Scenario:** Represents the current state of the rice value chain before project implementation and the integration of biochar.
- **Target Scenario:** Reflects the expected situation after project implementation, including biochar production and soil incorporation.

This comparison allows for a thorough evaluation of the impact of biochar integration on the sustainability of the rice value chain.

Figure 10. The initial interface sheet of the tool allows the user to select the crop to be assessed for biochar potential and sustainability analyses.



Source: Authors' own elaboration.

Table 6. List and description of Sustainability Indicators (SI) developed for the AI4Biochar project

Pillar	Indicator	Description	Unit	Inputs
Environmental sustainability	GHG emissions	It compares the emission of main GHG (CO ₂ , CH ₄ , N ₂ O) of the scenario without project (BASELINE) with the emissions of the scenario with project (TARGET)	g/year	<p>BASELINE scenario:</p> <ul style="list-style-type: none"> • Current amount of value chain products (e.g. yields and harvested surface or production quantity); • Current end use of coproducts (residues); • Transport (distance) from the field to the processing unit of agricultural products. <p>TARGET scenario:</p> <ul style="list-style-type: none"> • Pyrolysis unit locations and related distances from fields; • Transport (distance) of biochar from the pyrolizer unit to the application site/markets; • Details of biochar use (e.g. if applied to soil, or sold to markets).
	Non GHGs emissions	It compares non-GHG (CO, NO _x , SO _x , PM _x) emissions of the scenario without project (BASELINE) with the emissions of the scenario with project (TARGET)	g/year	
Social sustainability	Job creation	It assesses the net job creation as result of biochar production and use	h/year	Working hours for drivers/loaders for biomass/biochar transport, number of employees in biochar production units
Economic sustainability	Income generation	It describes the net income from the sale, barter and/or own consumption of biochar, including feedstock (residues), by self-employed households/individuals. Moreover, it assesses the estimated sector-driven income for the community within the target area	USD/year	<ul style="list-style-type: none"> • Biochar market overview (prices, etc.) • Estimated revenues from sale of biochar • Change in income for personnel in charge of biochar production unit

Source: Authors' own elaboration.

The assessment tool is structured with interlinked calculation sheets. One worksheet contains references, data sources, and key reference values (e.g. emission factors) used in the assessment, while another worksheet stores data input for the project data.

The calculation worksheets are structured to reflect the different natures of the indicators being assessed. For GHG and non-GHG emission indicators, separate sheets are used for the baseline and target scenarios to accurately capture the changes resulting from biochar implementation. However, for indicators related to job creation and income generation, a single worksheet is sufficient for each because the baseline value is zero in both cases; no biochar production occurs in the baseline scenario, and therefore there is no impact on jobs or income generation.


The analysis is guided by a series of assumptions that inform the assessment process. These assumptions are derived from literature sources to establish baseline parameters for key processes and resource flows. They are then refined and validated through consultations conducted during field visits. This iterative approach ensures that the assessment framework is grounded in established knowledge while also reflecting the specific context and practical insights from local stakeholders involved in the rice and biochar value chains. Building on this foundation, the Sustainability Indicator (SI) assessment tool was developed to model both the baseline and target scenarios tailored to the Vietnamese context.

For the baseline scenario, surveys conducted during a field mission indicated that the totality of rice straw residues were left in the field in the targeted district, while rice husks were entirely removed with rice harvests. Residue burning practices are also significant in the target province: field data analysis revealed that half of rice straw residues were burned directly on the field, while the totality of rice husks were burned at the mill, highlighting substantial residue management challenges.

For the target scenario, about one third of rice straw residues were assumed to be incorporated into the soil, reflecting improved agricultural practices. On the other hand, the incorporation of rice husks remained unchanged at 0 percent. Assumptions for burning practices indicated a reduction to 40 percent of rice husks burned at the mill and complete elimination of rice straw burning on the field.

As discussed earlier, the analysis assumes that the mill used in the baseline scenario is equipped with a biochar unit, or in close proximity, to minimize unnecessary transport costs. As a result, the distances related to biochar transport would remain the same for both the baseline and target scenarios. Concerning the use and transportation of biochar, it was assumed that the totality of the produced biochar would be returned to the field. No biochar was assumed to be sent to market (Figure 11).

Figure 11. The Data Input Sheet of the SI Calculator is used to input defining variables of the rice value chain and the main assumptions that describe the value chain in baseline and target scenarios.



Parameter (annual)	Value	Unit	Source
Field/parcel surface	1.35315	ha	AI prototype
Current population employment rate, men and women, age group 20-64	68.6	%	National statistics
Crop yield	5.754261974	tonne/ha	AI prototype
Unitary water requirement		m ³ /ha	GIS Layer
Number of harvests	1	-	Interview/primary data
Residues production rate - rice husks	0.25	tonne/tonne _{crop}	FAO BEFS/Primary data
Residues production rate - rice straw	1.33	tonne/tonne _{crop}	FAO BEFS/Primary data
BASELINE share of residues left in the field - rice husks	0%	%	Survey (mission)
BASELINE share of residues left in the field - rice straw	100%	%	Survey (mission)
BASELINE share of residues incorporated into soil - rice husks	0%	%	Assumption
BASELINE share of residues incorporated into soil - rice straw	0%	%	Assumption
BASELINE share of residues burned - rice husks (at mill)	100%	%	Survey (mission)
BASELINE share of residues burned - rice straw (on field)	50%	%	Survey (mission)
Total residues transport distance (from production site to mill)	30	km	Assumption
TARGET share of residues incorporated into soil - rice husks	0%	%	Assumption
TARGET share of residues incorporated into soil - rice straw	30%	%	BEFS calculations
TARGET share of residues burned - rice husks (at mill)	40%	%	Assumption
TARGET share of residues burned - rice straw (on field)	0%	%	Assumption
Share of produced biochar sent BACK TO FIELD	100%	%	Assumption

Source: Authors' own elaboration.

The Sustainability Indicator for GHG emissions is based on a life cycle assessment (LCA) approach, which evaluates environmental impacts across the entire value chain. The LCA framework allows for a systematic comparison between the baseline and target scenarios, accounting for factors such as resource use, emissions, and residue management practices, thereby capturing both direct and indirect effects of integrating biochar into the rice value chain.

The worksheets for GHG emissions indicator in the baseline scenario include sections for residues transport (from crop to mill), residues incorporation into soil, residues burning, and a final calculation for the overall value chain GHG emissions. For the target scenario, the sections are residues transport (from field to pyrolysis unit), residues incorporation into soil, pyrolysis for biochar production, residues burning, biochar transport (from pyrolysis unit back to field or to market), biochar application to soil, and a calculation of the overall value chain GHG emissions. It was assumed that transportation is carried out using diesel-powered trucks.

The methodology for calculations and reference values follows the guidelines of the Intergovernmental Panel for Climate Change (IPCC, 2006), considering CO₂ fossil, CO₂ biogenic, CH₄ fossil, CH₄ biogenic, N₂O, and CO₂-equivalent (CO₂eq) to ensure comprehensive and standardized assessments.

The same structure applies to the non-GHG emissions indicator, which includes sections for emissions of CO, NO_x, SO_x, and PM_x across the same stages of the value chain.

Figure 12. Result section of the *baseline* scenario calculation sheet for the GHG emission indicator. Positive GHG emissions are detected for the specific plot delineated by the AI4Biochar tool.

RICE VALUE CHAIN		
GHG Emissions Indicator (BASELINE scenario)		
RESIDUES BURNING		
Amount of residues burned - rice husks (at mill)	1,946.59	kg
Amount of residues burned - rice straw (on field)	5,177.94	kg
Total amount of residues burned	7,124.54	kg
CO ₂ biogenic	-	g
CH ₄ biogenic	43,459.68	g
N ₂ O	-	g
CO ₂ eq	1,213,878.67	g
OVERALL VALUE CHAIN		
GHG emissions Grand Total	1.21806	tonne CO₂eq

Source: Authors' own elaboration.

Figure 13. *Target* scenario calculation sheet for the GHG emissions indicator showing the GHG emission/removals obtained but this time with biochar production and incorporation into the soil.

RICE VALUE CHAIN		
GHG Emissions Indicator (TARGET scenario)		
Fuel use (diesel) from pyrolysis unit back to field	0.00	MJ
Fuel use (diesel) from pyrolysis unit from pyrolysis unit to market	-	MJ
Total fuel use	85.70	MJ
CO ₂ fossil	7,298.82	g
CO ₂ biogenic	-	g
CH ₄ fossil	11.33	g
CH ₄ biogenic	-	g
N ₂ O	0.04	g
CO ₂ eq	7,583.31	g
BIOCHAR APPLICATION TO SOIL		
Optimal application of biochar to soil	10.00	tonne/ha Optimal biochar application rates for mitigating global warming and increa
Applied biochar	3.53	tonne
Applied biochar per ha	2.61	tonne/ha <small>When biochar production is less than the optimal application rates (i.e. 10</small>
Total C (before application)	2.40	tonne
Total C stored in soil	2.36	tonne
CO ₂ eq sequestred	8.67	tonne
OVERALL VALUE CHAIN		
GHG emissions Grand Total	-11.780258	tonne CO₂eq

Source: Authors' own elaboration.

For the job creation indicator, the tool considers two key parts of the value chain: the transport of residues from the field to the pyrolysis unit, as well as biochar production and biochar transport. These directly contribute to employment opportunities, both through the physical handling of residues and to the operational aspects of biochar production and distribution.

Field surveys indicate that a biochar production plant with a capacity of 3 000 tonnes per year in the region employs 15 people year-round. In addition, the transportation of rice straws to the biochar plant and the delivery of biochar back to the fields are also expected to generate employment for truck drivers. Rice husks, in our baseline scenario, are assumed to be readily available for pyrolysis.

These transportation-related jobs were estimated based on the average loading capacity of trucks used in Vietnamese farming operations and calculations of the actual distances between existing rice mills and the centroid of each plot delineated by the AI tool.

Figure 14. The *job creation* indicator shows the estimated amount of work, and related job positions created, by the biochar production at plot level.

RICE VALUE CHAIN			
Job Creation Indicator			
	Value	Unit	Notes
RESIDUES TRANSPORT (from field to pyrolysis unit, truck)			
(BASELINE) Working hours - Drivers/loaders	0.077864	h/year	(total residues transported/loading capacity)*2/average vehicle speed
(TARGET) Working hours - Drivers/loaders	0.367829	h/year	(total residues transported/loading capacity)*2/average vehicle speed
BIOCHAR PRODUCTION			
Employees in biochar unit	0.017634	#	biochar produced*coeff
Working hours - Aggregated workers	46.55317	h/year	assumed 8 hours/day, 330 days in 1 year
BIOCHAR TRANSPORT			
Working hours - Drivers/loaders	0.14107	h/year	(total biochar produced/loading capacity)*2/average vehicle speed*di
OVERALL VALUE CHAIN			
Jobs before project	0.077864	h/year	These values can also be expressed in terms of the number of positions created. However, since we are currently referring to the individual parcel rather than the entire region, we believe it is more appropriate to express them in terms of work hours. Expressing this indicator's value them in terms of job positions, would return meaningful values only at provincial or regional
Jobs after project	47.06206	h/year	
Job generated	46.9842	h/year	



Source: Authors' own elaboration.

It should be noted that the most meaningful scale for assessing the impact on social conditions through job creation is likely at the district or regional level, representing the aggregation of plot-level results.

The income generation indicator focuses on the market price of biochar in Viet Nam, which, according to data collected during the field mission, is approximately USD 450 per tonne. This price was then used to estimate revenue generation, factoring in the lifespan of the biochar unit, which is assumed to be 20 years. Based on the above, the project calculated the potential revenue and, subsequently, the income generated, assuming that income is 20 percent of the total revenue for this kind of industrial applications. This approach allows for an assessment of the financial benefits derived from biochar production and sale, as well as the potential economic impact on local communities involved in the value chain.

Step 6: Integration of the sustainability indicators to the spatial layer

The output information from the Sustainability Indicators (SIs) calculator is fully compatible with the AI tool, facilitating further analysis and integration within the project's framework. The calculator generates a set of conversion factors that can be directly applied in a GIS environment. Resulting maps are created by applying these coefficients and implementing the associated algorithms to each rice plot. This integration relies on two spatially derived variables: first, the quantity of rice produced on each plot, and second, the distance from each plot to the rice mill, which is assumed to be the optimal location for establishing a biochar production plant.

More details on the application of the tool to the Tri Ton case study, including limitations of the model and uncertainty of the analysis, will be made available in a separate FAO Statistical Working Paper.

3.4 Results from the AI4Biochar tool application to Tri Ton

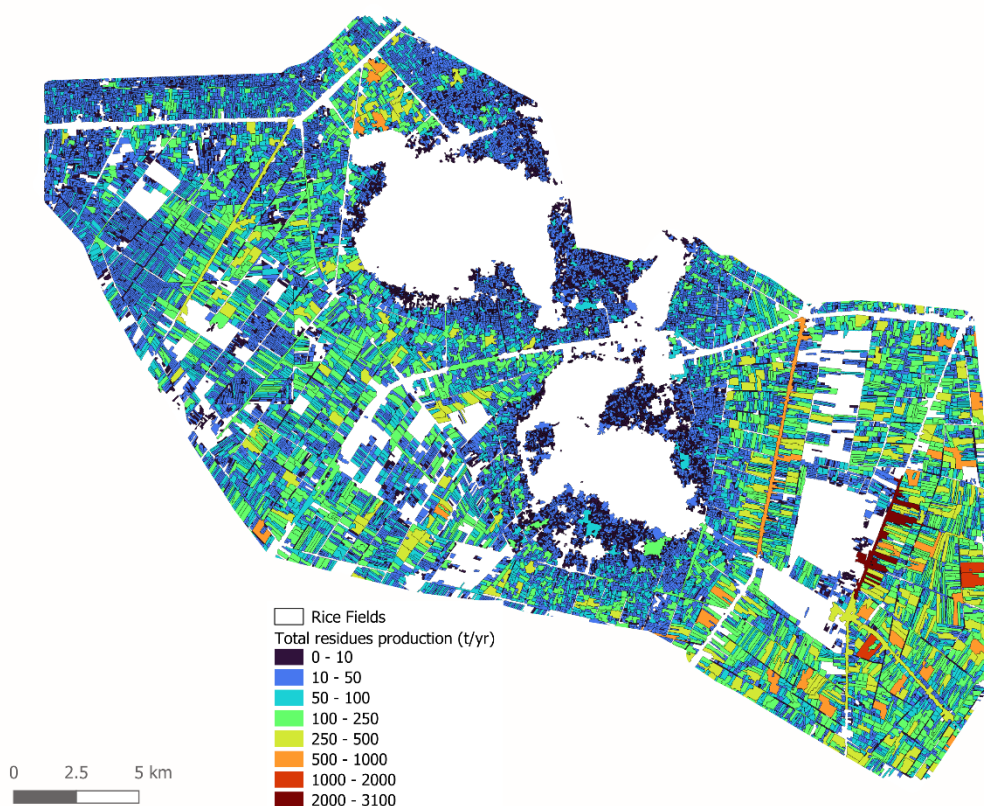
The output information from the Sustainability Indicators (SIs) calculator is fully compatible with the AI tool, facilitating further analysis and integration within the project's framework. The calculator generates a set of conversion factors that can be directly applied in a GIS environment. Resulting maps are created by applying these coefficients and associated algorithms to each rice plot in the Tri Ton district. This integration relies on two spatially derived variables: first, the quantity of rice produced on each plot, and second, the distance from each plot to the rice mill, which is assumed to be the optimal location for establishing a biochar production plant.

The production per plot serves as a key input variable for calculating the amount of crop residues generated from each rice field. The analysis estimates a total of 901,540 tonnes of rice residues produced in the reference year 2020, with approximately 85 percent of this biomass originating from rice straw and the remainder from rice husks.

GHG emissions and potential for mitigation

The crop residues left in the field and their burning typically make for a limited share of the GHG emissions from agriculture (FAO, 2025). Nonetheless, this analysis estimated a strong potential for mitigation which goes well beyond the compensation for the emissions from burning as it incorporates the carbon sequestration from the production of biochar.

Figure 15. Distribution of rice residues per rice plot in the Tri Ton district



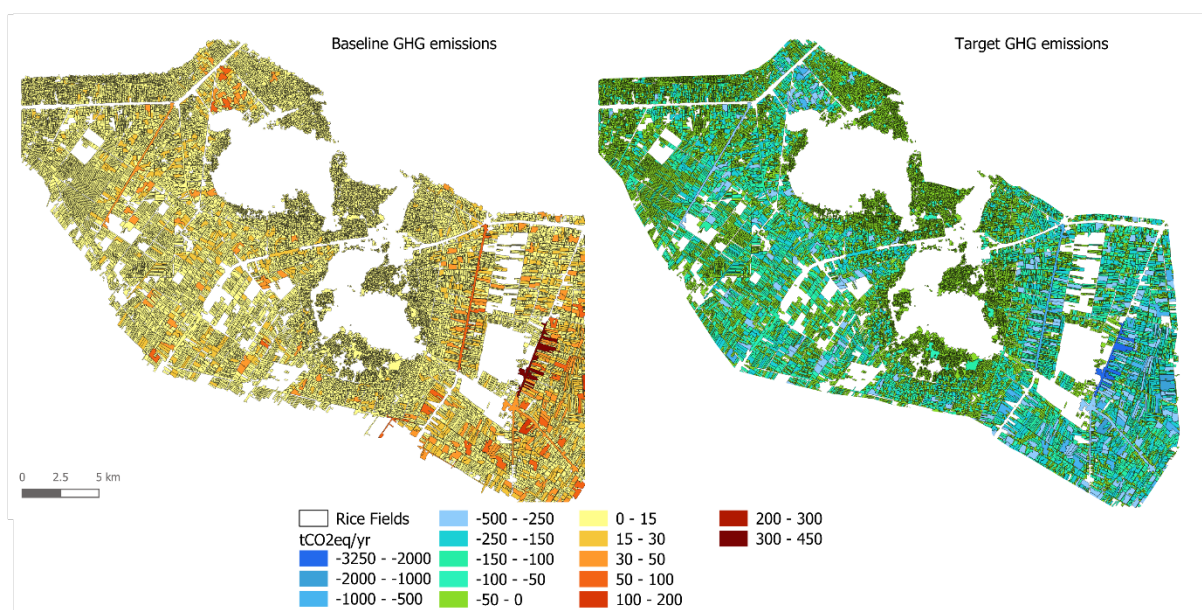
Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.
Source: Authors' own elaboration.

Table 7. Summary results of GHG emissions in the baseline and target scenario, 2020 reference year

	Baseline Scenario	Target Scenario
	tCO ₂ eq/year	
Mean per ha of rice	2	-18
Totals	89 097	-864 345

Source: Authors' own elaboration.

Figure 16. GHG emissions (in t CO₂eq per year) in the baseline (left graph) and target (right graph) scenarios per rice plot in the Tri Ton district



Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.

Source: Authors' own elaboration.

Our analysis estimated baseline emissions amounting to nearly 90 kilotonnes (kt) of CO₂eq and a striking ten-fold potential for total removals. On average per ha of rice, this would correspond to 1.8 tCO₂eq/year in the baseline scenario and -17.7 tCO₂eq/year in the target scenario (Table 7 and Figure 16).

Non-GHG emissions

The Department of Crop Production (MAE) estimates that around 50 million tonnes of crop residues per year are produced. For most farmlands, a significant amount of agricultural or crop residues is burned in open areas after harvest to prepare fields for the next planting season. For rice straw, up to 80 percent of residues are burned in the country (UN Environment and Clean Air Asia, 2020). Open burning greatly contributes to air pollution, affecting the environment, livelihood, health, and overall well-being of the public. Air pollution is the 4th leading cause of global mortality, accounting for 6.7 million deaths (HEI, 2020) in 2019. By 2060, the resulting health costs are estimated to be around USD 2.2 trillion annually (OECD, 2016), with additional possible costs due to reduced agricultural yield, cancelled or affected flights, and reduced tourism rates due to poor air quality. Non-GHG co-pollutants such as carbon monoxide (CO),

nitrogen oxides (NO_x), sulphur oxides (SO_x), and particulate matter (PM) are harmful pollutants released alongside greenhouse gases from sources like power plants, factories, and vehicles. Unlike GHGs, which primarily contribute to climate change, these co-pollutants directly impact human health and the environment. For instance, exposure to SO_x can lead to respiratory problems and contribute to acid rain formation while PM emissions from vehicle, industrial processes, construction activities, and natural sources like wildfires and more in general, biomass burning, can cause respiratory issues and cardiovascular diseases. These pollutants are emitted during open burning of biomass residues and are linked to impacts on human health and environmental degradation. In addition to CO, NO_x, SO_x, and PM, several Persistent Organic Pollutants are also known to be emitted as a consequence of biomass burning (Stockholm Convention, 2008). Information on these pollutants is much scarcer than for GHG gases and detailed reference levels for Viet Nam are not readily available. However, the severity of the issue is well known in South-East Asia, and as early as in 1999, the ASEAN Secretariat emanated specific regulation (known as the “Zero Burning Policy”) that provides guidelines to member countries on how to reduced agricultural residue burning in the Region. Viet Nam established the Vietnam Clean Air Partnership (VCAP) with the mission to gather and mobilize individuals and social organizations in the country to participate in activities serving the improvement of air quality, including alternatives to open field burning of agricultural residues.

In national as well as regional on zero burning guidelines in fact, alternative to open burning of rice residues contemplate the incentivization of biochar production. To discourage agricultural residue burning, farmers must be guided on the best technological options for crop residue management, and to increase knowledge on rice straw value chains and business models. Further assessment of options must be done, given that the economic viability of technological solutions must be considered for different situations. The analysis carried out in the context of the AI4Biochar project led to assess the emission of non-GHG air pollutants in the case study area as a baseline, and to estimate the potential emission reduction attainable with the introduction of biochar production from rice residues, as an alternative to open field burning.

Table 8 summarizes the results of the analysis, showing that the implementation of a biochar project would ensure an important abatement of the emissions from all these harmful pollutants. In absolute terms, this is particularly relevant for the emissions from CO (Figure 17).

In addition, connected to open burning of rice straw, is the emission of Persistent Organic Pollutants (POPs), highly harmful chemical compounds that are recognized as carcinogenic and imposing great hazard to human health. These compounds are emitted at a considerable rate when rice straw burning takes place, and their impacts is on human health and biodiversity, as these chemicals travel far distances in the air. In the north of Viet Nam, open burning of rice straw has resulted in higher concentrations and variations of toxic PAHs and nitro-PAHs in the air, including benzo[a]pyrene which can cause cancers and reproductive diseases (WHO, 2000).

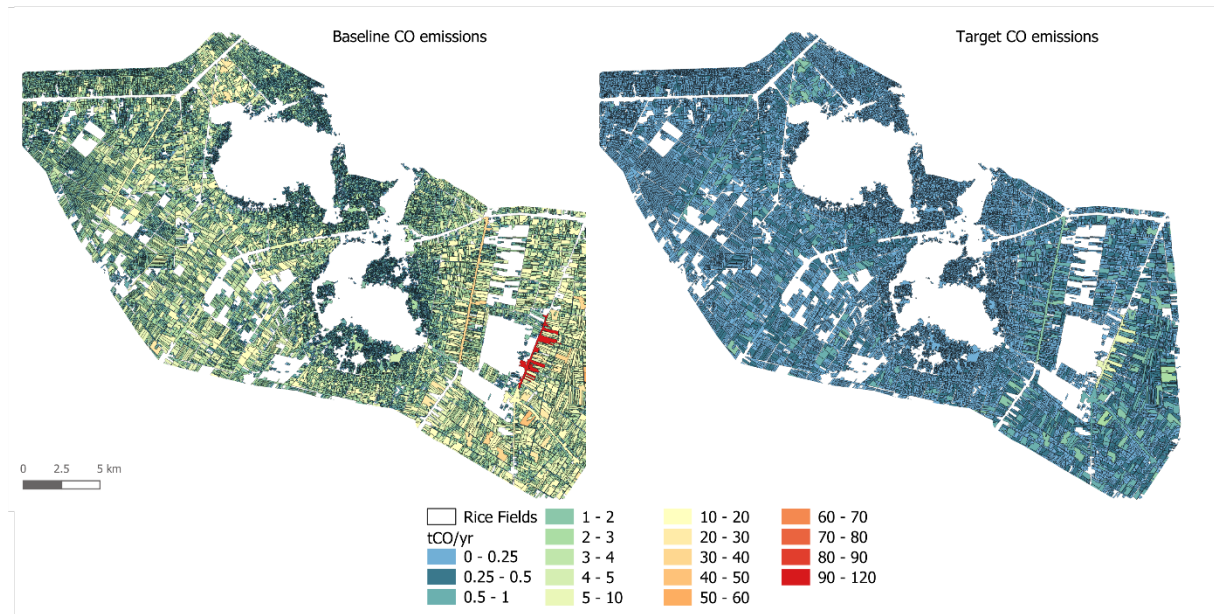
Table 8. Emissions of non-GHG pollutants and relative abatement with biochar project implementation

	Baseline	Target	Net
	t gas/year		
CO	34 824	1 809	-95%
NOx	1 201	169	-86%
SOx	262	0	-100%
PM	2 976	0	-100%

Source: Authors' own elaboration.

According to Clean Air Asia (UN Environment and Clean Air Asia, 2020), studies in Ho Chi Minh City shown that the risk of respiratory hospital admissions increased from 0.7 percent to 8 percent for every 10 $\mu\text{g}/\text{m}^3$ increase of measured air pollutants. Higher sensitivities were observed among women. High concentration of PM in Ho Chi Minh City is responsible for around 200 deaths every year.

Figure 17. Emissions from CO (in tonnes/year) in the baseline and target scenarios per rice plot in the Tri Ton district



Note: Refer to the disclaimer on page ii for the names and boundaries used in this map.
Source: Authors' own elaboration.

According to UNEP et. al (2021), the key barriers to the adoption of zero burning strategies in Viet Nam include the following:

- Lack of awareness of locals on effective crop residue management (e.g. people are used to the idea that burning is the fastest way to clear land, remove pests, and generate fertilizer in the form of ash);
- Financial constraints due to low income from agriculture sector, which hinders hiring of additional labour for the handling of residues;
- Limited applicability of farm-scale technologies (i.e. chain production development is not suitable in smaller farms; mismatch in scale; technical progress for some farmers is challenging);
- Inadequate production planning to ensure sustainability of post-harvest waste management; and
- Lack of specific policies and clear implementation guidelines in the collection, handling, and use of residues.

The evident reduction in non-GHG air pollutants emissions as a consequence of biochar production underlines the relevance of this practice and technology to respond to the challenges and key barriers to the adoption of a zero burning mechanism. Biochar is a product that would allow collection at farm level but processing at centralized level, thus relieving the

farmers from biomass collection costs, labour and planning needs. In addition, returning biochar, with its high organic carbon content and nutrient concentration compared to ashes, creates an opportunity for farmers to understand the value of this practice in terms of soil quality improvement, and related yield and productivity benefits.

Potential for job creation and revenue generation

The results of the sustainability indicator calculations for job creation and revenue generation are reported in Table 9. It is important to note that these values refer to the entire surface area of the Tri Tôn area, while the distance from the field to the biochar processing unit is equal to the sum of the average distances of each parcel to the biochar processing unit.

To calculate the total number of permanent jobs created, we used the standards set by the International Labour Organization (ILO). The ILO defines decent work in part through its standards on annual leave, weekly rest days, and working hours. Workers are entitled to at least three weeks (21 days) of paid annual leave per year and must have at least one rest day⁷ (24 consecutive hours) per week, which amounts to approximately 52 rest days annually.⁸ Given a standard year of 365 days, subtracting 52 weekly rest days and 21 days of paid leave, a worker would have approximately 292 working days per year, assuming no additional public holidays or other forms of leave are included. Based on this standard, dividing the total labour hours of 3 426 119 by 8 hours per workday and 292 working days per year, we estimate approximately 1 467 permanent jobs created.

Table 9. Sustainability indicator calculations for job creation and income generation and related data

Variable	Aggregate value
Job creation (hour/year)	3 426 119
Revenues generation (USD/year)	23 260 007
Distance to mill (m)	348 046 589
Physical area of rice (ha)	48 646
Harvested area of rice (ha)	94 187
Total rice production (t/year)	570 594
Total biochar (t/year)	258 445

Source: Authors' own elaboration.

Labour force in Viet Nam in 2022 was 51 705 000 people, while the total population was 99 465 000.⁹ The unemployment rate in Viet Nam in 2023 was about 2.75 percent. This means that 50 283 112 people were employed. In the Tri Tôn district, where the population was 117 431 in 2019,¹⁰ applying the same proportions results in a workforce of 61 044.29 people,

⁷ For more information, see: International Labour Organization (ILO) - [Decent Work Agenda](#)

⁸ For more information, see: International Labour Organization (ILO) - [Holidays with Pay Convention \(Revised\), 1970 \(No. 132\)](#)

⁹ For more information, visit <https://www.gso.gov.vn/wp-content/uploads/2024/03/Sach-BC-Dieu-tra-LDVL-2022-English.pdf>

¹⁰ For more information, visit https://www.citypopulation.de/en/vietnam/admin/an_giang/891__tri_t%C3%B4n/

with approximately 59 368 employed people in the district. Therefore, the impact of the 1 467 jobs created would correspond to a 2.4 percent reduction in the unemployed population.

To evaluate the impact of the establishment of the biochar value chain in the Tri Ton district from an economic standpoint, this analysis considered the contribution to the local GDP of producing biochar from rice residues. An indicator of revenue generation intended as the contribution to local GDP of the proposed interventions, namely a biochar value chain taking full benefit of the existing agricultural residue pool in the case study province, has been devised and applied to this analysis.

The GDP per capita for An Giang in 2022 was USD 3 227 000 000,¹¹ while for Tri Tôn district, the total GDP is USD 156 904 376. The revenues generated from the establishment of the biochar value chain in Tri Tôn is USD 23 260 007, which represents a significant contribution to the local economy. This would correspond to approximately 14.8 percent of the total GDP of Tri Tôn, highlighting the substantial economic impact of the biochar value chain in the region.

3.5. Other tools, projects and incentives to support the development of the biochar sector

Viet Nam employs a variety of tools to support the development and implementation of biochar production and application, which are crucial for advancing the biochar sector. These tools range from technical and research-focused instruments to financial and policy-oriented frameworks.

Biomass mapping and resource assessment tools, including Geographic Information Systems (GIS), are used to assess and identify areas abundant with agricultural residues, such as rice husks, coconut shells, and corn cobs, which are critical feedstocks for biochar production. The combination of GIS and biomass assessment ensures that biochar facilities are strategically located near reliable and high-quality biomass sources, reducing transportation costs and environmental impacts. It can also identify agricultural lands that would benefit most from biochar application, based on factors like soil type, fertility levels, and irrigation infrastructure. Additionally, GIS is used to monitor the environmental impacts of biochar projects, such as improvements in soil carbon levels and reductions in greenhouse gas emissions from open-field burning of residues.

In regions like the Mekong Delta, where rice production generates millions of tonnes of biomass annually, GIS mapping and biomass assessment have proven to be transformative. They support the establishment of biochar production hubs, reduce the environmental damage caused by residue burning, and improve the livelihoods of local farmers by creating green jobs.

Another tool to promote the development of the biochar sector in Viet Nam is the internet-based platform Biochar Vietnam.¹² This is an online platform to serve as a repository of information on biochar in Viet Nam. It provides resources, news, and updates on the sector. It was established under the financial support of the State Secretariat for Economic Affairs (SECO) through the United Nations Industrial Development Organization (UNIDO) at the end of 2023 to share and disseminate knowledge, lessons, and initiatives in biochar research, production, and trade activities over the country. The platform undertakes a range of activities to support its mission, including introduction of clean and cost-effective pyrolysis technology

¹¹ For more information, visit https://en.wikipedia.org/wiki/An_Giang_province

¹² For more information, visit <https://vncpc.org/en/>

from Switzerland, enhancing local manufacturing capabilities, and conducting pilot applications of pyrolysis systems.

Financial mechanisms, such as subsidies, grants, and tax incentives, are also available to support the adoption of biochar, particularly for small-scale farmers and businesses. These diverse financial mechanisms, ranging from government grants and carbon credit programmes to impact investing and crowdfunding, help fuel the growth of the biochar industry in Viet Nam.

One key financial instrument is green finance. The Vietnam Green Credit Programme (VCG), supported by the State Bank of Vietnam, provides favorable loan terms for biochar producers involved in sustainable agriculture and waste management. Companies focusing on carbon sequestration through biochar production, such as Biocare Projects, can access low-interest loans and grants to purchase necessary equipment and scale their operations. Additionally, biochar projects can generate carbon credits by sequestering carbon in biochar. These credits can be sold on international carbon markets, offering a continuous revenue stream. For instance, projects like the Rice Husk to Premium Biochar Project can sell carbon credits, creating additional financial support to fund biochar production and related activities.

The Vietnamese government also provides critical financial support through grants and subsidies. The Ministry of Agriculture and Rural Development (currently Ministry of Agriculture and Environment), through programmes such as the Agricultural and Rural Development Support Fund, allocates grants to projects that promote sustainable agricultural practices, including biochar usage.

The Biochar for Sustainable Soil (B4SS) project has received funding from MARD (currently MAE) to conduct field trials and establish biochar production units. Additionally, Viet Nam's National Renewable Energy Programme supports biochar initiatives by offering subsidies to projects that convert biomass into biochar, reducing emissions and fostering renewable energy solutions.

Public-private partnerships (PPPs) also provide a significant financial tool for biochar projects. In Viet Nam, State-Owned Enterprises (SOEs) like the Viet Nam Oil and Gas Group (PetroVietnam) have partnered with biochar producers to finance large-scale production plants. These PPPs bring together government support and private sector expertise to establish sustainable biochar production facilities. Projects in the Mekong Delta are a prime example, where local governments and private companies collaborate to produce biochar while enhancing agricultural practices and environmental outcomes.

The Vietnam Bank for Social Policy (VBSP) is one such institution offering microloans to farmers who wish to adopt biochar production methods, particularly in the Mekong Delta where rice husks are abundant. Farmers can use these loans to purchase pyrolysis units and scale up biochar production. In addition, farmer cooperatives can pool resources to finance biochar production. These cooperatives, often supported by international development funds from organizations like the Asian Development Bank (ADB) and the World Bank, allow farmers to collaborate on biochar production and share the costs and benefits.

International climate finance mechanisms also play a pivotal role. Programmes from organizations like USAID, the Global Environment Facility (GEF), and the Green Climate Fund (GCF) provide grants and low-interest loans to biochar projects that aim to address climate change, improve soil fertility, and promote sustainable agriculture. The Biochar for Carbon Removal and Improved Livelihoods project in the Mekong Delta, for example, has received funding from such programmes, enabling the development of biochar production facilities and supporting local farmers. Furthermore, bilateral aid from countries like Australia, through the Australian Department of Foreign Affairs and Trade (DFAT), has funded several biochar initiatives, particularly those focused on rural development and carbon sequestration.

4. Relevant policies and institutional arrangements for promoting biochar investments and responsibilities

4.1. Agricultural and environmental policies supporting a biochar economy

Viet Nam has implemented a range of agricultural and environmental policies aimed at fostering sustainable development, addressing climate change, and promoting a circular economy. These policies offer a conducive environment for the integration of biochar into efforts to enhance agricultural productivity, improve waste management, and conserve natural resources.

In the agricultural sector, Viet Nam's policies focus on boosting productivity while mitigating environmental impacts. The Sustainable Agriculture Development Programme emphasizes reducing the use of chemical fertilizers, improving soil health, and increasing crop yields. Biochar, as a natural soil amendment, supports these objectives by enhancing nutrient retention, reducing the need for synthetic inputs, and promoting organic farming practices. The National Green Growth Strategy (NGGS) also prioritizes eco-friendly farming methods and innovation to achieve low-carbon growth. Incorporating biochar into farming systems aligns with NGGS goals by sequestering carbon and lowering greenhouse gas emissions. Furthermore, Viet Nam's policies to expand organic agriculture through subsidies and certifications create an opportunity for biochar to play a critical role in enhancing organic soil quality and fertility.

Environmental policies further reinforce the role of biochar in addressing climate and waste management challenges. The Law on Environmental Protection (2020) establishes a framework for waste reduction, recycling, and efficient resource use, encouraging the utilization of agricultural residues for biochar production. Similarly, the National Climate Change Strategy promotes measures to reduce greenhouse gas emissions in agriculture and waste sectors. For instance, using biochar in rice paddies to reduce methane emissions aligns closely with these goals. Additionally, Viet Nam's Decree on Waste Management mandates recycling and the sustainable management of agricultural and organic waste, making biochar production a practical solution to convert biomass residues into valuable agricultural resources.

Viet Nam's commitment to a circular economy is reflected in the National Action Plan for Circular Economy, which emphasizes resource reuse and recycling across sectors. Biochar production exemplifies these principles by transforming biomass waste into high-value agricultural inputs. Policies encouraging the sustainable use of agricultural residues also complement these efforts, addressing the issue of residue burning and turning waste into an asset. Although primarily targeting plastics, Viet Nam's broader waste reduction initiatives provide a supportive framework for waste-to-resource innovations like biochar.

4.2. Responsibilities in government for planning a sustainable biochar market

Ministry of Agriculture and Environment

The Ministry of Agriculture and Environment (MAE) plays a key role in developing a sustainable biochar market in Viet Nam, aligning it with goals for sustainable agriculture, environmental protection, and climate change mitigation. MAE integrates biochar into national agricultural strategies by promoting its use as a soil amendment to improve fertility, reduce chemical fertilizer reliance, and boost productivity. It also coordinates with other ministries to ensure consistency with Viet Nam's sustainability and climate targets.

To grow the biochar market, MAE supports value chain development, facilitates public-private partnerships, and provides incentives for investment in biochar production. It also leads awareness campaigns and training programmes to educate farmers and stakeholders about biochar's benefits and application techniques, especially in rural areas.

MAE mobilizes financial resources by advocating for subsidies, tax incentives, and concessional financing, while collaborating with international donors to fund projects. It also monitors biochar initiatives by collecting data and evaluating their impacts, using tools like AI4Biochar to optimize resource allocation and improve policies, ensuring long-term success.

Ministry of Agriculture and Environment establishes environmental regulations for biochar production, ensuring sustainable biomass sourcing, pollution control, and ecosystem safety. It collaborates with research institutions to set standards on heavy metals, pH, and carbon content for environmentally safe biochar. Monitoring biochar's impact on carbon sequestration, soil health, and pollution reduction is a key task.

Ministry of Industry and Trade

The Ministry of Industry and Trade (MOIT) supports the development of biochar production infrastructure, including pyrolysis plants and decentralized units, by fostering technology transfer and innovation through collaboration between enterprises, research institutions, and international partners.

Integrates biochar into renewable energy strategies, leveraging byproducts like bio-oil and syngas from pyrolysis as renewable energy sources. Policies promoting co-generation systems can enhance energy efficiency in biochar facilities, contributing to Viet Nam's transition to cleaner energy and reducing fossil fuel dependency.

Develops export strategies, ensures compliance with international standards, and promotes biochar through trade fairs and networking events. Financial incentives, such as tax breaks and subsidies, are vital to reducing investment barriers and encouraging private sector involvement in biochar production and supply chains.

MOIT monitors the biochar market's economic performance by analyzing production trends, trade dynamics, and value chain challenges.

Ministry of Finance

The Ministry of Finance (MOF) allocates budgetary resources for research, capacity building, and pilot projects, prioritizes biochar in development goals, and ensures alignment with targets for sustainable development, rural livelihoods, and climate change mitigation working with MAE to prioritize impactful initiatives.

To encourage investments, MOF provides financial incentives such as tax exemptions for biochar producers, subsidies for farmers, and import duty reductions on production equipment. It also designs concessional financing schemes, including low-interest loans and grants, to support small-scale producers and rural biochar projects.

MOF mobilizes domestic and international investments by creating a favorable climate to attract funding from private investors, development banks, and organizations.

Ministry of Science and Technology

The Ministry of Science and Technology (MOST) promotes research and development (R&D) in biochar production, encouraging projects that improve efficiency and functionality using local feedstocks like rice husks and bagasse. It provides grants and incentives to drive innovation in agriculture, water filtration, and carbon sequestration applications.

MOST establishes technical standards and certification systems for biochar quality and safety, ensuring reliability and boosting market confidence.

Local government

Local government raises farmer awareness of biochar benefits for soil health and GHG mitigation through training and demonstrations, encouraging its use in agriculture.

Identify and manage biomass resources, such as rice husks and sugarcane bagasse, coordinating their collection and processing into biochar; allocate land, infrastructure, and resources for biochar production facilities, supporting investment in rural areas.

Financial incentives, like subsidies and tax breaks, are offered to encourage adoption, while collaborations with farmers, cooperatives, and businesses ensure initiatives meet community needs.

5. How the AI4Biochar tool can contribute to advancing the biochar sector and recommendations for MAE

The biochar sector in Viet Nam holds significant potential to contribute to sustainable agriculture, climate change mitigation, and waste management. However, its growth is hindered by various challenges that require strategic interventions from the Ministry of Agriculture and Environment (MAE) and the government.

Emerging technologies like AI can enhance the sector's potential by streamlining processes and optimizing decision-making. Specifically, the AI4Biochar tool could significantly enhance the processes involved in the biochar sector by providing data-driven insights, improving efficiency, and facilitating better decision-making across the entire biochar value chain. By utilizing AI and machine learning technologies, the tool streamlines various aspects of biochar production, resource management, environmental impact assessment, and market development:

- **Optimizing Biochar Production:** AI4Biochar can analyze and optimize the production process by using data from various sources, such as on feedstock availability and production methods. The tool can inform the sustainable amount of feedstock residues which could be used for producing biochar based on the type of biomass being used and the local conditions. This optimization can result in more efficient use of resources, improved sustainability of the sector and reduced costs.
- **Enhancing Residues Management:** The tool can assist in efficiently managing biomass feedstock by monitoring supply and demand patterns for different agricultural residues such as rice husks, coconut, and coffee residues. By analyzing data on biomass availability, AI4Biochar can help identify regions with abundant feedstock and optimize logistics for transporting raw materials to biochar production facilities. This could reduce waste and lower costs for biochar producers while ensuring a steady supply of feedstock.

In the Mekong Delta—where rice husk and straw are abundant—the tool can highlight areas where biochar production can be integrated with rice farming, reducing transportation costs and maximizing resource efficiency.

AI4Biochar can analyze transportation networks and recommend the most efficient routes for biomass collection and biochar distribution. This reduces logistics costs and carbon emissions. For example, if a biochar facility in Tây Ninh province sources feedstock from multiple locations, the tool can calculate the shortest, most cost-effective routes to reduce fuel consumption and transportation costs.

- **Environmental Impact Assessment:** AI4Biochar can also play a vital role in environmental monitoring and impact assessment. The tool can provide updated assessments of the environmental benefits of biochar. This includes estimating reductions in greenhouse gas emissions and other sustainability indicators. This helps stakeholders make informed decisions about the most effective usages of biochar.
- **Resource Allocation and Decision-Making:** AI4Biochar assists stakeholders in making informed decisions about where and how to invest in biochar production. By using machine learning algorithms, the tool helps monitor demand for biochar and identify areas for further investment. This allows producers, investors, and policymakers to allocate resources more effectively.

AI4Biochar can help policymakers design effective subsidies and incentives by identifying the financial gaps that hinder biochar adoption. If the tool finds that

smallholder farmers are reluctant to use biochar due to high upfront costs, the government can introduce targeted subsidies, tax exemptions, or low-interest loans to encourage adoption.

- **Capacity Building and Education:** AI4Biochar can be integrated into training and educational platforms. The tool can simulate different biochar production scenarios. This will help build the capacity of stakeholders, ensuring that they have the skills and knowledge needed to make the most of biochar technologies.
- **Integrating with Other Industry Tools:** AI4Biochar can be integrated with other digital tools, such as resource mapping platforms, environmental monitoring systems, and financial modelling software, to create a more comprehensive approach to biochar production and market development. By sharing data across these platforms, AI4Biochar can help stakeholders gain a holistic view of the biochar sector and improve cross-sector coordination, ensuring that biochar's potential is fully realized in a sustainable manner.

In the future, the AI4Biochar tool could be further developed to also support **financial decision-making** by providing data on the potential return on investment (ROI) for new biochar production projects. The tool can help analyze production costs, market conditions, and environmental benefits to help investors assess the financial viability of biochar ventures. From the government's perspective, the tool can help identify the sectors and regions where financial support will contribute to make the biochar sector more efficient. Additionally, AI4Biochar can assist in monetizing the environmental benefits of biochar, which can be used to attract impact investors focused on sustainability.

Collaboration among ministries

By aligning policies, mobilizing resources, and streamlining implementation, ministries can maximize the socio-economic and environmental benefits of biochar across sectors such as agriculture, energy, and the environment. Coordination among ministries is crucial to integrate biochar into national and sectoral strategies:

- MAE can incorporate biochar into sustainable agriculture policies, emphasize its role in climate change mitigation; MOIT can promote biochar in renewable energy plans, ensuring its widespread adoption.
- MOF shall collaborate to allocate funds and design financial incentives, including tax reductions, subsidies, and concessional financing. These measures ensure financial resources are directed to priority areas identified by technical ministries like MOST and MAE, fostering market development.
- MOST and MAE should work together to establish technical standards for biochar production and application which ensure product quality, safety, and market access, supporting both domestic and international trade.
- Research and innovation require joint efforts from MOST, MAE, and MOIT to promote technological advancements in biochar production and usage.
- Capacity building is another essential area where MOET and MAE can collaborate. By integrating biochar-related topics into training programmes and curricula, ministries can create a skilled workforce to advance biochar production and adoption across the country.
- Data sharing among ministries is critical for effective planning and decision-making. Tools like AI4Biochar can provide a centralized platform for analyzing biomass availability, market demand, and environmental impacts, ensuring evidence-based policies.

Collaboration with other groups of stakeholders

Collaboration with non-governmental stakeholders such as private companies, research institutions, non-governmental organizations (NGOs), farming communities, and international development agencies is essential to fully realize the potential of the biochar sector. Partnerships with private companies like GreenID Vietnam, Vietnam Biocarbon, or international firms specializing in pyrolysis technologies can accelerate the development of advanced biochar production systems and value-added products, such as biochar-based fertilizers, water filtration systems, or animal feed additives. These companies can also help establish dedicated production facilities and create tailored biochar solutions for specific agricultural or industrial needs, leveraging their resources and technical expertise. Additionally, NGOs like SNV Netherlands Development Organization and Helvetas Vietnam can play a critical role in promoting biochar adoption at the grassroots level. These organizations can engage smallholder farmers, cooperatives, and self-help groups to raise awareness about biochar's benefits for soil health, crop productivity, and climate resilience. Participatory approaches led by these NGOs—such as co-creation workshops with rural stakeholders—can help develop sustainable business models that align with local conditions and needs. Furthermore, partnerships with academic institutions like Vietnam National University of Agriculture (VNUA) or Can Tho University allow for rigorous research on biochar's environmental and economic impacts while providing technical support to stakeholders across the value chain. International development agencies can also contribute funding, capacity-building programmes, and global expertise to scale up biochar initiatives in Viet Nam.

ANNEX: Policy recommendations for the government to foster a functioning biochar market in Viet Nam

To overcome obstacles and challenges and take advantage of growth opportunities for the biochar sector, these are some high-level recommendations for the MAE and the Government from the authors of this report:

- MAE and the government shall formulate a comprehensive national biochar strategy to provide a roadmap for sector development. This strategy should include integrating biochar into national programmes for sustainable agriculture, GHG mitigation, and circular economy initiatives, and should be based on results from unbiased and recognized decision-support tools.
- MAE and the government should establish an inter-ministerial task force to coordinate policies and programmes. This task force can oversee the integration of biochar into national strategies and ensure alignment among stakeholders.
- Securing funding from national and international sources is essential to support infrastructure development, R&D, and market expansion. Monitoring and evaluation frameworks should be established to track the progress of biochar initiatives, assess their environmental and economic impacts, and identify areas for improvement.
- Market Development: Efforts to create and expand the biochar market are crucial. Public awareness campaigns, training programmes, and demonstration projects can educate farmers and businesses about biochar's benefits and applications. Establishing certification standards for biochar products will ensure quality and build consumer confidence. The government can also support the development of robust supply chains and distribution networks to improve market access for producers.
- Capacity Building and Collaboration: Capacity building should focus on equipping farmers, cooperatives, and agribusinesses with the knowledge and skills needed to adopt biochar technologies. Collaboration between government agencies, private enterprises, and research institutions can foster innovation and accelerate the sector's growth. Partnerships with international organizations can provide technical expertise, funding, and access to advanced technologies, further enhancing Viet Nam's biochar capabilities.
- Research and Innovation: Investing in research and development (R&D) is critical for addressing technical challenges and exploring innovative applications of biochar. R&D efforts should focus on developing cost-effective and efficient production technologies tailored to local biomass resources. Long-term studies on biochar's impact on soil health, crop yields, and carbon sequestration can strengthen its value proposition. Expanding research into biochar's potential uses in water purification, construction materials, and renewable energy storage can diversify its applications and markets.
- Developing biochar product standards and certification systems in Viet Nam requires a collaborative approach. The government can work with research institutions, universities, and international organizations to establish baseline standards tailored to the country's agricultural and environmental context. Input from industry stakeholders, including biochar producers and users, is essential to ensure the practicality and effectiveness of these standards. Additionally, creating a regulatory framework that mandates compliance with biochar standards will encourage producers to prioritize quality and safety.

- Integration into the Circular Economy: Biochar production should be promoted as a byproduct of renewable energy generation from agricultural and organic waste. Aligning biochar initiatives with Viet Nam's circular economy strategy can emphasize resource efficiency and waste reduction, transforming agricultural residues into valuable resources.

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