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BIOmass for COkemaking DEcarbonization

Project Deliverable Report

D1.2

Policy brief on enablers and barriers for biomass in the steel sector

Public

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1 Summary

The European Union's ambitious climate goals, including achieving carbon neutrality by 2050, demand significant reductions in CO_2 emissions across all industrial sectors. Steel production is one of the most carbon-intensive industries, with cokemaking contributing heavily to its environmental footprint. Biomass presents a compelling alternative to fossil coal for cokemaking, aligning with circular economy principles and offering the potential to lower emissions substantially. However, despite its advantages, the integration of biomass in the steel sector faces technological, logistical, and regulatory hurdles. This policy brief explores these enablers and barriers in detail and provides actionable recommendations for policymakers and stakeholders to facilitate the transition towards more sustainable steelmaking.

2 Introduction

The steel industry, which accounts for approximately 7% of global CO_2 emissions, is under growing pressure to adopt greener production methods. Among the most carbon-intensive processes is cokemaking, where fossil coal is traditionally used to produce metallurgical coke, a crucial material in the blast furnace route of steelmaking. Considering the European Green Deal and the EU's goal of achieving carbon neutrality by 2050, identifying sustainable alternatives to fossil coal has become a priority. Biomass, derived from agricultural and forestry residues, offers a promising pathway for decarbonization. When converted into biochar through pyrolysis or torrefaction, biomass can partially replace fossil coal in coke-making, reducing greenhouse gas emissions while promoting circular economy principles. However, the adoption of biomass at an industrial scale faces significant challenges, including variability in biomass quality, logistical constraints, and economic competitiveness. The BIOCODE project aims to address these challenges by demonstrating the feasibility of substituting up to 10% of fossil coal with biochar in industrial coke-making processes. By leveraging locally available biomass and integrating advanced pre-treatment technologies, BIOCODE seeks to showcase a scalable solution that balances environmental sustainability with industrial efficiency. This document explores the critical factors influencing the integration of biomass in steel production, analyzing both opportunities and challenges. It aims to provide stakeholders with strategic insights and practical solutions to facilitate the sector's shift towards sustainable practices and reduced carbon emissions.

3 Enablers

3.1 Abundance of biomass resources in Europe

Biomass availability is a key enabler for its integration into industrial processes like steelmaking. Europe generates vast quantities of agricultural and forestry residues that remain underutilized. For example:

- **agricultural residues**: in Italy, olive pruning alone produces over 1.16 million tons annually, while vine wood and straw are also widely available. These materials are particularly abundant in Mediterranean countries.
- **forestry by-products**: northern and central European countries, such as Sweden and Germany, contribute substantial amounts of forestry residues, including sawdust, wood chips, and bark.

The BIOCODE project focuses on the utilization of locally available biomass resources in southern Italy, particularly around the Acciaierie d'Italia (AdI) steel plant in Taranto. While, regarding the continental area, the use of commercially available biochar is currently under evaluation. Through a comprehensive analysis, detailed described in deliverable D2.2, nine biomass types were selected based on their availability, proximity to the production site, and potential application in the cokemaking process. These biomasses include:

- **olive pruning residues (branches and trunks)**: a significant by-product of the olive oil industry, widely available across Apulia.
- **vine wood**: generated from vineyard pruning, common in the region.
- **straw**: a residue from cereal cultivation, abundant in agricultural zones.
- **wood from pallets and packaging materials**: a reliable industrial source of biomass.
- **olive pomace**: a by-product of olive oil extraction, with high potential for biochar production.
- **pine**: as a pruning residues, a cultivar widely found in Mediterranean woodlands and urban areas.

The regional availability of these resources near steel production sites reduces transportation emissions and costs, creating a decentralized and sustainable supply chain. This local sourcing aligns with the circular economy model, turning biomass waste into valuable inputs for industry. Additionally, biomass pricing remains competitive compared to fossil coal, especially when factoring in the environmental costs of the latter.

3.2 Supply chain development

The suitability of biomass for cokemaking relies on advanced processing technologies to address its inherent variability. The untreated biomass presents several challenges that hinder its direct use in industrial applications such as cokemaking. Preprocessing steps are critical for improving logistics and ensuring compatibility with industrial-scale operations. In addition, modern biomass processing facilities are increasingly incorporating gas recovery systems to capture by-products like syngas and bio-oil generated during pyrolysis. These gases can be used to power the pre-treatment process itself, reducing external energy demands and providing additional energy inputs for the steelmaking process, supporting sustainability and energy efficiency. This closed-loop approach maximizes resource utilization and aligns with circular economy principles. Furthermore, the implementation of pre-treatment facilities creates new employment opportunities in rural and industrial areas, particularly in roles such as biomass collection, processing, and technology management. These treatment processes are critical enablers for the steel sector's decarbonization, making biomass a competitive and sustainable alternative to fossil coal. Without them, the integration of biomass at an industrial scale would face significant technical, economic, and logistical challenges. These challenges include[1]:

- **high moisture content**: raw biomass often contains significant amounts of water, which lowers its energy density and increases transportation and storage costs. High moisture also reduces efficiency during thermal conversion processes.

[1] **BioCoDe project**. RFCS Grant Agreement No: 101112264 - Deliverable 2.2 - *Biomass and biochar selection and characterization*

- **low carbon content**: compared to fossil coal, biomass has a lower proportion of fixed carbon, a critical parameter for producing high-quality coke.
- **high volatile matter**: the presence of volatiles in untreated biomass can negatively impact coke formation, leading to lower yield and quality.
- **structural variability**: biomass comes in diverse forms and compositions (e.g., olive branches, straw, wood), which require standardization before integration into industrial processes.

Treatment technologies enable biomass to overcome these limitations, effectively transforming it into a viable substitute for fossil coal. These processes enhance biomass properties, aligning them with the stringent requirements of industrial applications such as:

- **improved energy density**: pre-treatments like torrefaction remove moisture and volatiles, concentrating the energy content of biomass and making it comparable to fossil coal.
- **enhanced carbon content**: by increasing the proportion of fixed carbon, treatment processes improve the performance of biomass in coke making.
- **logistical efficiency**: densification processes like briquetting reduce the volume of biomass, making it easier and more cost-effective to transport and store.
- **consistency in quality**: pre-treatments standardize biomass feedstocks, reducing variability and ensuring predictable performance during industrial processing.

Below is an overview of the most relevant processes:

- **Torrefaction** is a thermochemical process in which biomass is heated to temperatures between 200°C and 300°C under an oxygen-limited environment. This process reduces moisture content and removes volatile organic compounds, improving the biomass' energy density; enhances grindability, allowing biomass to mimic the physical characteristics of coal, which is critical for its integration into metallurgical processes; produces a material commonly referred to as "biocoal" or "torrefied biomass", which is hydrophobic and easier to store, transport, and process. Since biomass exhibits the highest release of volatile matter below 300°C, torrefaction has proven to be a cost-effective pretreatment for increasing carbon content.

- **Pyrolysis** involves the thermal decomposition of biomass at temperatures exceeding 400°C in the absence of oxygen. This process generates three main products: **biochar**, a carbon-rich solid with enhanced fixed carbon content and reduced volatile matter, suitable for coke-making; **bio-oil**, a liquid by-product that can be refined into renewable fuels or chemicals and **syngas (synthetic gas)**, a mixture of hydrogen, methane, and carbon monoxide, which can be used as an energy source within the steel plant. The flexibility of pyrolysis allows for the optimization of conditions to maximize biochar yield while capturing energy from the bio-oil and syngas, contributing to process efficiency and reducing overall emissions.

- **Steam explosion** is an emerging biomass pre-treatment technology involving high-pressure steam followed by rapid depressurization. This process breaks down the lignocellulosic structure of biomass, making it more porous and reactive; increases the availability of fixed carbon for the cokemaking process; produces a material with improved grindability and reduced moisture content, making it easier to integrate into existing coal blends. Steam explosion is particularly effective for agricultural residues with high lignin and cellulose content, such as olive branches and vine wood.

- **Mechanical preprocessing**, including chipping, grinding, and briquetting, is essential to standardize biomass feedstocks. **Chipping and grinding** ensures uniform particle size, improving the consistency of subsequent thermal treatments. **Briquetting** compresses biomass into dense, uniform shapes that enhance transport and storage efficiency while minimizing dust generation.

3.3 Environmental and economic benefits

The integration of biomass into cokemaking processes provides significant environmental and economic advantages, reinforcing its role as a critical enabler for sustainable steel production. By replacing a portion of fossil coal with biochar, biomass utilization directly addresses the twin goals of reducing carbon emissions and fostering economic resilience. For what concerns environmental benefits:

1. *Reduction in CO_2 emissions*

The substitution of biomass-derived biochar for fossil coal significantly reduces greenhouse gas emissions. Biomass is considered carbon-neutral because the CO_2 emitted during its combustion is equivalent to the amount absorbed by plants during their growth. This results in:

- a net decrease in CO_2 emissions during cokemaking processes.
- contribution to the European Union's Green Deal targets for carbon neutrality by 2050. In practical terms, replacing fossil coal with biochar reduces the overall carbon footprint of steel production, addressing one of the most critical environmental challenges faced by industry.

2. *Improved waste management*

Biomass utilization aligns with circular economy principles by transforming agricultural and forestry residues into valuable inputs for the steel sector. This approach mitigates:

- environmental pollution caused by the open burning of residues such as straw and olive pruning, which is a common practice in many regions.
- the need for landfill space, as agricultural waste is repurposed instead of being discarded.

3. *Lower particulate and sulfur emissions*

Compared to fossil coal, biochar contains significantly lower levels of sulfur and other impurities. This results in:

- reduced emissions of sulfur oxides (SO_x), which are harmful pollutants contributing to acid rain.
- improved air quality in and around steel production facilities.

For what concerns economic benefits:

1. *Cost savings through local sourcing*

The BIOCODE project focuses on using locally available biomass. This strategy:

- reduces transportation costs and associated emissions, as biomass is sourced close to steel production sites.
- mitigates the volatility of global fossil coal markets by creating a decentralized supply chain.

2. *Creation of new economic opportunities*

The development of a biomass supply chain supports local economies by creating jobs in:

- biomass collection and preprocessing, such as chipping, grinding, and briquetting.
- production of biochar and other value-added products from agricultural residues. Farmers and agro-industrial operators benefit from additional revenue streams, as residues traditionally considered waste are monetized.

3. *Energy recovery potential*

During the thermal conversion of biomass into biochar, by-products such as syngas and bio-oil are generated. These can be repurposed as:

- renewable energy sources to power biomass pre-treatment facilities, reducing dependency on external energy inputs.
- fuels for on-site use in steel plants, enhancing energy efficiency and cost savings.

4. *Resilience to fossil fuel price fluctuations*

As the global fossil fuel market becomes increasingly volatile, adopting biomass as a renewable feedstock reduces the steel sector's vulnerability to price shocks. This ensures more predictable production costs and long-term economic stability.

The dual environmental and economic benefits of biomass integration create a positive feedback loop. By reducing emissions, improving waste management, and creating local economic opportunities, the steel industry can undergo transition to a more sustainable model while maintaining competitiveness. Furthermore, aligning industrial practices with EU policies unlocks funding opportunities and ensures compliance with increasingly stringent environmental regulations. The use of biomass not only addresses immediate challenges in decarbonizing steel production but also establishes a foundation for long-term sustainability. This positions the steel industry as a leader in adopting innovative solutions to combat climate change while driving regional economic development.

3.4 Policy and funding support

The European Union's policy framework plays a pivotal role in enabling the adoption of biomass in industrial processes. Through targeted regulations and financial incentives, the EU provides a structured environment that reduces the risks and barriers associated with transitioning from fossil fuels to bio-based alternatives. Key policies and programs include:

- *European Green Deal*

The Green Deal prioritizes the decarbonization of energy-intensive industries such as steelmaking, emphasizing the urgent need to reduce CO_2 emissions. Biomass, as a carbon-neutral resource, aligns with this objective by providing a renewable alternative to fossil coal. This policy not only encourages industries to adopt low-carbon technologies but also promotes research and innovation in sustainable practices like those undertaken by the BIOCODE project. By integrating biomass, steelmakers could meet the ambitious targets set by the Green Deal while maintaining their competitiveness.

- *Renewable Energy Directive (RED II)*

RED II mandates increased use of renewable energy sources across EU member states. Biomass, categorized as a renewable resource, is specifically highlighted for its potential to replace fossil fuels in industrial applications. This directive supports the use of bio-based materials like biochar in high-emission sectors and encourages the development of standardized certification systems to ensure the sustainable sourcing of biomass. By providing a clear regulatory framework, RED II reduces uncertainties and creates a stable foundation for the future integration of biomass in cokemaking.

- *Funding Mechanisms*

Financial support is a critical enabler for overcoming the high initial costs of transitioning to biomass. Programs like the Research Fund for Coal and Steel (RFCS) have been instrumental in supporting projects like BIOCODE that develop and demonstrate biomass-based technologies and facilitating collaborations between industrial stakeholders, research institutions and policymakers. This funding reduces financial barriers and accelerates the development and scaling of innovative biomass solutions.

Policy frameworks and funding mechanisms are enablers because they provide:

- regulatory clarity: clear guidelines encourage industries to adopt sustainable practices without fear of non-compliance.
- economic incentives: subsidies and grants offset the costs of adopting new technologies, making the transition more feasible.
- market stability: long-term policies create a predictable environment that encourages investment in bio-based solutions.

By reducing financial and regulatory risks, these initiatives create a favorable ecosystem for integrating biomass into the steel sector.

3.5 Synergies with circular economy principles

Biomass utilization embodies the principles of a circular economy by transforming waste into value-added resources. This approach not only reduces environmental impact but also fosters collaboration across sectors, driving innovation and economic growth. Key synergies include:

1. *Waste valorization*

Agricultural and forestry residues, such as olive branches, straw and vine wood, are often discarded or burned, contributing to environmental pollution. Through biomass utilization:

- these residues are repurposed as feedstocks for biochar production, reducing waste,
- the steel sector benefits from a renewable resource that mitigates its reliance on finite fossil fuels.

This transformation turns a liability (waste) into an asset (industrial input), aligning economic and environmental objectives.

2. *Sector collaboration*

Integrating biomass into industrial processes fosters partnerships between agriculture, forestry and steel industries. These collaborations:

- encourage knowledge sharing and innovation, as stakeholders work together to optimize biomass sourcing, preprocessing, and utilization.

- create shared economic benefits, as farmers and forestry operators gain new revenue streams while steelmakers access sustainable feedstock.

By strengthening these interconnections, biomass integration supports regional economic resilience and sustainability.

3. Sustainability and resource efficiency

By using locally available biomass, projects like BIOCODE address resource scarcity while reducing transportation emissions. Additionally:

- the closed-loop nature of biomass utilization ensures minimal waste generation and maximized resource efficiency.
- this approach contributes to long-term sustainability goals by reducing environmental degradation and promoting renewable energy use.

The alignment with circular economy principles is an enabler because it:

- **reduces environmental footprint**: by repurposing waste and minimizing resource extraction, industries can achieve significant environmental benefits.
- **enhances economic viability**: circular practices reduce costs associated with waste disposal and resource sourcing, improving overall efficiency.
- **builds public and market trust**: demonstrating commitment to sustainability enhances the reputation of companies and attracts investment.

Biomass utilization not only aligns with circular economy goals but also demonstrates how industrial sectors can innovate to achieve both environmental and economic sustainability.

4 Barriers

While biomass holds immense potential for decarbonizing steel production, its integration faces several barriers that must be addressed to enable widespread adoption. These barriers are primarily technical, logistical, and regulatory in nature, creating challenges that impact both the feasibility and economic viability of biomass utilization.

4.1 Technical challenges

One of the primary technical challenges lies in the properties of biomass-derived biochar, which often fail to match the performance of fossil coal. Biochar typically has a lower fixed carbon content and lacks plasticity, which can compromise the quality of the coke produced. This discrepancy necessitates careful adjustments in blending ratios and operational parameters, increasing complexity and costs. Furthermore, raw biomass is characterized by high moisture content and volatile matter, both of which reduce thermal efficiency during pre-treatment and cokemaking. Moisture content lowers the energy density of biomass, while volatile matter leads to higher evolution of gases during processing. These issues make pre-treatment technologies, such as torrefaction and pyrolysis, essential; however, these processes introduce additional costs and energy requirements. Another significant technical barrier is the heterogeneity of biomass feedstocks. Agricultural residues such as olive and pine prunings, straw, and vine wood exhibit substantial variability in chemical composition and physical characteristics. Differences in carbon content, ash levels and grindability make it difficult to standardize feedstocks, which in turn affects the consistency of the biochar produced. This variability poses challenges for large-scale operations, where uniformity is critical for maintaining product quality.

4.2 Logistical and economic barriers

Logistical challenges are a major obstacle to the large-scale adoption of biomass. Unlike fossil coal, which is typically concentrated in specific locations, biomass is widely dispersed across rural areas. Collecting and transporting biomass to centralized processing facilities requires extensive infrastructure and inter-operational storage point, leading to higher operational costs. Storage presents another difficulty, as biomass with high moisture content must be carefully handled to prevent degradation and maintain its quality. Economic barriers further compound these issues. Advanced technologies such as torrefaction, pyrolysis, and densification are essential for transforming raw biomass into a usable form, but these processes involve significant capital and operational expenditures. Energy-intensive pre-treatment methods increase the overall cost of biomass, making it less competitive compared to fossil coal. The fact that the biomass needs further treatment, and the yield will be in the range of 30 to 50% will double or even triple the price. This increase is not yet covered by the pricing of CO_2 certificates. Additionally, biomass faces stiff competition from other industries, such as bioenergy production and agriculture, which often offer higher prices for the same materials. This competition reduces the availability of biomass for industrial applications like steelmaking, further driving up costs.

4.3 Regulatory and market constraints

The lack of a harmonized regulatory framework across EU member states creates uncertainties for steelmakers attempting to integrate biomass into their processes. Different countries define "sustainable biomass" in varying ways and implement inconsistent certification systems for sourcing and processing. These discrepancies make it difficult for industries to navigate regulations, slowing the adoption of biomass-based solutions. Economic incentives for biomass adoption are also insufficient to overcome the high costs of transitioning from fossil fuels. While research funding programs like RFCS are instrumental in supporting innovation, they do not provide the financial assistance needed for scaling up biomass infrastructure. This leaves many small and medium enterprises without the resources to invest in necessary technologies, and larger companies often prioritize cost efficiency over sustainability in the absence of strong incentives. Public perception adds another layer of complexity. Concerns about the environmental impacts of large-scale biomass collection, such as deforestation or habitat disruption, can create resistance to its adoption. Furthermore, fears about reduced availability of agricultural residues for traditional uses, such as soil conditioning, may lead to opposition from stakeholders in other sectors.

These barriers collectively hinder the scalability and feasibility of biomass integration in the steel sector. Technical limitations reduce the quality and reliability of biochar, logistical and economic challenges drive up costs, and regulatory inconsistencies create uncertainty for industries looking to transition. Addressing these barriers will require coordinated efforts, including investments in advanced technologies, the development of efficient supply chains and the establishment of clear and harmonized regulatory frameworks. Only by overcoming these challenges can the full potential of biomass be realized, paving the way for a sustainable future in steel production.

5 Recommendations

To fully exploit the potential of biomass in the steel sector, the BIOCODE project and similar initiatives must continue to address technical, logistical, and regulatory barriers while exploring new pathways for improvement. Current efforts focus on enhancing biomass pre-treatment technologies such as torrefaction and pyrolysis to improve the properties of biochar, ensuring it meets the rigorous requirements of cokemaking. However, additional advancements could include the integration of energy recovery systems within pre-treatment facilities. By utilizing by-products like syngas and bio-oil generated during pyrolysis, the energy demands of the process could be reduced, making it more cost-effective and sustainable. The development of centralized biomass hubs near agricultural and forestry areas could also streamline the supply chain. These hubs would act as collection points for raw biomass, processing it into standardized forms suitable for transportation and industrial use. Such facilities could minimize logistical inefficiencies while ensuring a consistent feedstock supply. Within the scope of BIOCODE, this approach could involve closer collaboration with local agricultural operators to secure long-term biomass availability and reduce reliance on fossil coal. On the regulatory side, aligning biomass integration with EU directives such as the Renewable Energy Directive (RED II) and the European Green Deal remains critical. These frameworks already provide a supportive foundation, but additional harmonization of sustainability criteria and certification processes across member states could simplify adoption for industries like steelmaking. Within BIOCODE, the development of standardized protocols for evaluating and certifying the sustainability of biomass feedstocks would enhance both the environmental and economic viability of the initiative. Further research under BIOCODE could focus on testing and validating a broader range of biomass feedstocks to diversify the resource base. Alternative sources, such as agro-industrial residues and unconventional materials, could mitigate competition with other sectors while expanding the availability of feedstocks. Additionally, efforts to optimize biochar blends for cokemaking could refine operational parameters and improve performance, ensuring the compatibility of biochar with existing industrial processes. Lastly, the integration of biomass utilization into a circular economy framework offers promising synergies. By repurposing agricultural and forestry residues, BIOCODE is already demonstrating how waste can become a valuable resource for industrial applications. Future steps could include exploring co-benefits, such as using biochar in soil enrichment after its primary application in steelmaking or developing multi-sector collaborations to enhance the lifecycle benefits of biomass. These actions align with BIOCODE's overarching goals while paving the way for scalable, sustainable solutions in the steel industry. By addressing the remaining challenges and building on existing achievements, biomass can become a cornerstone of decarbonization efforts, positioning steelmaking as a leader in industrial sustainability.

6 Conclusions

The integration of biomass into the steel sector represents a significant step toward achieving the EU's decarbonization goals and advancing circular economy principles. The BIOCODE project aims to demonstrate the potential of locally sourced biomass as a renewable feedstock, capable of reducing reliance on fossil coal while providing environmental and economic benefits. By using advanced pre-treatment technologies, assessing the establishment of efficient supply chains and aligning with European regulatory frameworks, BIOCODE will lay the foundation for a more sustainable approach to coke production. Despite the progress made, challenges remain. Technical limitations, logistical complexities, and regulatory hurdles must be addressed to fully realize the scalability and viability of biomass in steelmaking. Continued research and collaboration are essential to optimize biomass pre-treatment processes, standardize feedstock quality, and integrate renewable energy recovery systems. Expanding the range of feedstocks and exploring multi-sector applications of biomass could further enhance its role in industrial decarbonization. BIOCODE represents not only a technical solution but also a model of cross-sector collaboration, leveraging local resources to create global impact. By addressing the remaining barriers and building on current successes, the project has the potential to transform the steel industry into a leader in sustainability and innovation, setting a benchmark for other energy-intensive sectors. The journey is ongoing, but the achievements thus far provide a solid foundation for a future where renewable resources drive industrial progress.