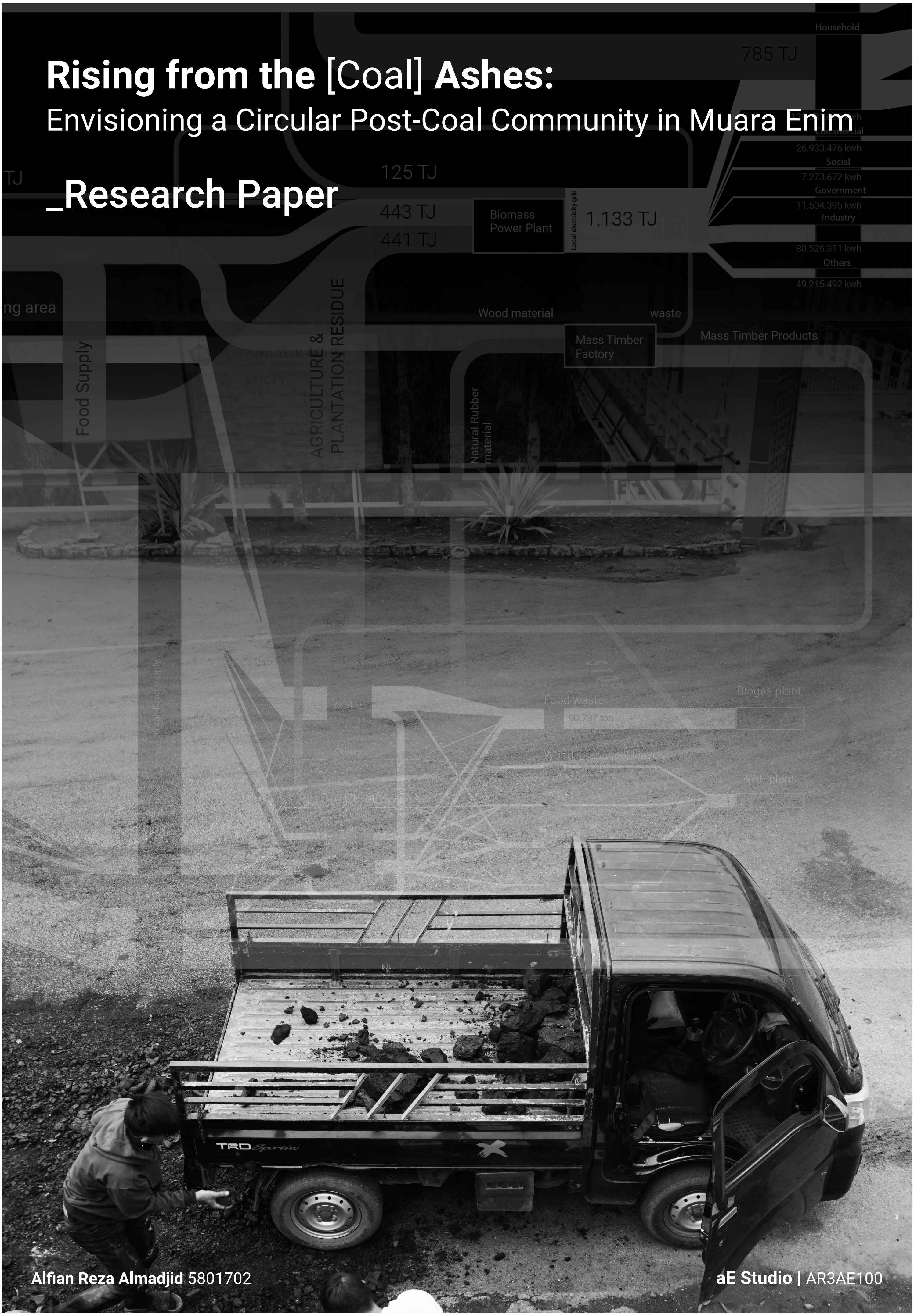
Rising from the [Coal] Ashes:
Envisioning a Circular Post-Coal Community in Muara Enim

_Research Paper



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ENVISIONING A CIRCULAR POST-COAL COMMUNITY IN MUARA ENIM WITH AGROFORESTRY

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ABSTRACT

Coal mining closure as part of the energy transition and global shift towards sustainability will have significant impacts on society, especially for coal-producing regions in developing countries that not only have to deal with the technical aspects but also the complex social, environmental, and economic dimensions. Comprehensive planning and intervention are therefore needed to ensure a just and seamless transition to a better life for the local people. This research paper investigates the possibility of (re)establishing agroforestry as the substitute activity in the soon-to-be-closed coal mining area in Muara Enim and its implications for its future urban metabolism as well as future architectural development. Material Flow Analysis is used as a method to map the problem and potential related to the energy and material in Muara Enim and how agroforestry practice can contribute to create better conditions. The results underscore a range of strategic interventions, from utilizing the former mining land to produce food, building materials, and energy sources to using the voids for aquaculture to fulfill the demand for local fish supply. Furthermore, the former mining infrastructures can also be repurposed and reused for new developments. The integration of those interventions will make way for architecture projects that are well integrated with their context, sources, and users.

KEYWORDS: *Energy Transition, Post-Coal Community, Agroforestry, Urban Metabolism, Material Flow Analysis, Muara Enim, Indonesia*

I. INTRODUCTION

1.1 Energy Transition & New Architectural Approach

As the world is grappling to avoid climate catastrophe and trying to shift toward sustainability, we need to rethink the way we use our natural resources and generate our energy. For far too long, our reliance on fossil fuels, deforestation, and unchecked industrial activities have taken a toll on our planet's ecosystems. The consequences are evident, from rising global temperatures and more frequent and severe natural disasters to the loss of biodiversity.

The urgency of addressing climate change and mitigating its impacts has prompted countries around the world to reassess their policies and initiate a transition to renewable energy. At the heart of this transition is the phasing out of coal, which has been the main discussion topic for the last decade since coal is the most polluting energy source, accounting for about 67% of the total global emissions related to energy in 2022 (ember-climate.org). While most Western countries have rapidly moved to solar panels and wind turbines, coal-producing countries in the global South are facing different challenges. Apart from the technical aspects of energy transformation, they must also address the complex social dimension that is intertwined around mining activity, as well as the degraded ecosystems and biodiversity resulting from extensive coal mining. After all, due to the lack of alternatives, those who suffered the most from the impact of coal mining also faced the greatest losses when the mines shut down (Stremke et al., 2022).

Drawing insights from other coal regions that experienced an economic and social disruption after their coal mining closure, comprehensive planning is therefore needed to ensure a just and seamless transition. Planning that is not only addressing the political aspects but also the spatial and cultural aspects. The fact that the main challenge for many coal regions in transition is to increase public awareness and convince citizens to engage in the transition (Commission, 2023), such planning also must include a tangible vision where people can see their future after the coal era. This crucial aspect is often overlooked in the current discourse on energy transition, which mostly revolves around economic feasibility and technological efficiency.

Architecture, as a practice closely related to the social and economic dimension of the community, can play a pivotal role in envisioning a better future in a soon-to-be-closed coal region. Beyond designing physical infrastructures, architects and designers can create a compelling narrative that engages local people and fosters a sense of hope and optimism in the community.

On the other hand, architecture can also be seen as an agent of depletion (Space & Foundation, 2021). The extraction of non-renewable resources for construction and the energy-intensive production of materials like concrete and steel are notable examples of how our practice is no better than the dirty coal mining activity. Not to mention the impact a building can have on producing waste material, pollution, and social injustice. Therefore, before engaging with the design and interventions, architects need to see this energy transition narrative as an opportunity to move beyond the conventional practice and focus more on integration, circularity, and regenerative principles. This entails ensuring that the facility/building we propose is well grounded within the context in every aspect and not just shifting environmental costs from one place to another. It can be started by analysing and envisioning the future conditions at the end of the coal era, where the projects will take place.

1.2. Study Case: Muara Enim

Indonesia, one of the biggest coal producers in the world, is among the nations that have pledged to phase out coal by 2050. That extractive industry that has shaped the nation's economic and environmental landscape will soon be ended with the issuance of Presidential Regulation No. 112/2022 (IESR, 2023). As one of the oldest (see Appendix 1) and most active mining regions in Indonesia, Muara Enim in Sumatra is among the first regions to experience the impact of that transition. Beyond its implications for the local economy, the closure of coal mining in Muara Enim will also profoundly affect the community since their mining areas are located very close to the residential settlements.

Although coal has played a crucial role in advancing the economic development of the region, this contribution comes at a cost, and the price is evident in the impact on the environment and the health of the local population. As the coal mining in Muara Enim employs the open-pit method, once a flourishing forest and agriculture land in the area has now transformed into an altered ecosystem characterized by the scars of coal mining (see Appendix 2). The deforestation and disruption of natural habitats not only diminish the aesthetic appeal of the region but also threaten the diverse range of species and make it more susceptible to natural disasters. Another apparent problem is the increased air pollution coming from the entire coal mining activity, from extraction and transportation to its combustion. The proof is not hard to see as the dust frequently blows into people's homes and covers the floor, the walls, and their goods. It is also supported by the fact that upper respiratory tract disease is the top disease in the region, accounting for 44.711 cases in 2022 or around 7% of the population (Regency, 2023).

With the inevitable end of the coal mining activity, the government and the coal mining company started to think about the future of the city and its people. While the government is more concerned about the economy and trying to establish an industrial zone, it is noteworthy that this industrial zone remains intertwined with the coal industry as its primary resource. In a similar fashion, PT Bukit Asam plans to transform Tanjung Enim into a tourism city. However, its implementation lacks coherent concepts and has limited participation from the public. The building of a coal museum, botanical parks, small enterprise & industrial center, and waterpark seem like tiny patches in a widely damaged land. It is no wonder that skepticism prevails among the locals and even government officials, highlighting the need for more comprehensive and inclusive planning (IESR, 2023).

Looking at the history of Muara Enim people which revolved around forestry and agriculture as well as their aspiration to have lands that can be cultivated again, the answer for the future of Muara Enim may lie in the degraded land that will be left at the end of coal mining activity. In 2004, the government and PT Bukit Asam launched a long-lasting agreement to promote productive land in the post-mined area (Enim, 2004). Although the realization and detailed plan keep changing following the ongoing mining exploration, the idea of restoring the open-pit mining area for agroforestry can be an opportunity to not only repair the ecological damage caused by the mining activities but also improve the livelihood of the community by providing suitable jobs, more sustainable food supply, and potential alternative energy. A research also shows that most of the reclamation areas in Tanjung Enim are suitable for agroforestry (Hermawan, 2016). Departing from that information, this thematic research will focus on investigating the possibility of (re)establishing an agroforestry framework in Muara Enim as the substitute for coal activity.

1.3. Research Question

This research paper is part of the graduation project that aims to develop an architectural intervention in a (soon-to-be-closed) coal mining region in Muara Enim. It is conducted to assist the design process with a clear understanding of urban metabolism in the area and give the toolkits needed to address the problems related to the closure of coal mining activities. To do so, it will answer the following question:

What are the current and future conditions of Muara Enim related to the ongoing mining activity, and how would the (re)introduction of agroforestry as the substitute activity help create a better urban metabolism?

II. METHODS

To answer the question mentioned above, two sections of research are conducted in parallel. The first segment is about understanding the potential of agroforestry, which is mostly gained through literature research. In this case, the book *An Introduction to Agroforestry* by P.K. Ramachandran Nair provides comprehensive insights, covering aspects from the definition of agroforestry to its varied practices across different regions. The second segment analyses the urban metabolism of Muara Enim to understand its problems in the future. The primary method used in this part is Material Flow Analysis, which is a methodology of mapping and quantifying the resource flows into and from a particular entity of human society (Graedel, 2019). However, to gain a more in-depth context of the site and collect the data needed, fieldwork to the area and interviews with different parties were conducted. Lastly, online sources and literature were examined to complement and make additional assumptions. Moving to the analysis part, both information on the agroforestry practice and the future condition of Muara Enim are analyzed to formulate interventions that help create a better urban metabolism that, in the end, will be the framework for the future development of this area.

III. RESULTS

3.1 Potentials of Agroforestry

3.1.1. Definition

Agroforestry can be understood as a land management approach that intentionally integrates trees with crops and/or animals (Nair et al., 2021). Though the term was coined a long time ago, it has different interpretations in various regions as reflections of their distinct characteristics and expectations associated with agroforestry. In tropical regions, the term is used to denote practices ranging from simple forms of shifting cultivation to complex hedgerow intercropping systems. Meanwhile in Western countries, agroforestry is practiced primarily for exploiting the biological interactions between trees and crops for a variety of environmental benefits (Nair et al., 2021). From this understanding, Nair concludes that there are three main attributes that are common in all agroforestry practices, namely productivity, sustainability, and adoptability.

Although the initial idea of Agroforestry is to improve productivity and overcome some conditions/constrains by forestry and agriculture practices (as shown in Appendix 3), The advantages of agroforestry stretch beyond individual farms or forested areas. It extends to the regional scale, providing a framework that is, therefore, productive, sustainable, and adoptable. To explore the potential of agroforestry as a replacement for the soon-to-be-closed coal industry, we can start by analyzing the ecosystem services that this system provides from the perspectives of economy, ecology, and socio-cultural (see Appendix 4).

3.1.2. Component/practices

In agroforestry, there are three basic components that form the landscape, namely trees or woody perennials, herbs (comprising agricultural crops, including pasture species), and animals. Of these, trees take center stage as the main actor in this land management system. While the presence of agricultural crops and animals is interchangeable, trees in agroforestry play a fundamental role in offering an array of benefits, such as providing shade, improving soil fertility, and enhancing water conservation. The interaction between woody perennials (trees and shrubs) and agricultural crops and/or animals then creates multiple combinations that are translated into different types of agroforestry practices, for example, Agrisilviculture (combination of trees with crops), Silvopastoral (combination of trees with pasture/animal), Agrosilvopastoral (combination of trees with crops and animal). That practice also spread across different scales, from a large forestry area to a small Homegarden, which had been part of Indonesian culture, especially in Java and Sumatra Island. The complete list and explanation of practice in tropical regions can be seen in Appendix 5.

3.2 Urban Metabolism in Muara Enim

3.2.1. Energy

Muara Enim is a region blessed with abundant sources of fossil fuels. From coal, natural gas, and the newly discovered oil source (VOI, 2022). Therefore, as predicted, almost all electricity supplies in the grid come from coal and its power plants. Only a small fraction of electricity is generated by solar panels to run farm irrigation, which is actually just an exemplary practice from the coal company’s CSR Program (JenderalEBTK, 2021). In reality, the use of solar panels doesn’t seem economically appealing to the people because, with the abundance of electricity supply from coal, any energy surplus from the solar panels cannot be sold back to the grid. This oversupply and inadequate infrastructure to distribute to other regions even hold the operation of the newly opened coal power plant in the region (Riyandanu, 2023).

Regarding the flow of electricity, PLN (State Owned Electricity Company) Muara Enim is estimated to supply 314.784.973 kWh of electricity to various users in Muara Enim and some neighboring regions in 2023. Among other categories, households in cumulative consumed the most electricity in total, with 139.331.628 kWh. Though each household may have a different way of using electricity, in the same climatic conditions in Sumatera island it is normally the Air Conditioners that use the most electrical power (Muhsin, 2020). The naturally hot conditions in Muara Enim drive people to put AC in most of the buildings. This condition seems to make sense when considering the unhealthy conditions from the coal activities that keep blowing dust; thus, opening windows and using natural ventilation in most cases are not ideal either.

Another source of energy produced locally is natural gas. As of 2021, there are 15.453 households in Muara Enim connected to the natural gas network (Resources, 2022). Given that there are 154.558 households in Muara Enim, it means that there are still around 90% of households relying on LPG for their kitchen. Based on observation and interviews, it is mainly due to the lack of infrastructure and the fact that some of the houses are made of timber, which they believe will be vulnerable if something happens with the gas pipe.

Although an oil source has been discovered in Muara Enim, the state-owned company has not initiated operations yet; therefore, gasoline and other fuels are imported from outside the region. They are mostly used for transportation, especially for coal mining operations, such as SUVs and buses for coal workers that can be easily spotted in and around the mining area during the day. Pertamina, as the state-owned company supplying fuels, reported that the allocation of gasoline in Muara Enim is 19.416 kiloliters in 2021 (Pertamina, 2021).

Based on the use of electricity, gas, and gasoline, we can estimate the emissions produced in the Muara Enim from the energy sector. The highest emission is from the use of electricity as it is generated by coal power plants. It accounts for 267.567 tons of CO_2eq, followed by the use of LPG and natural gas with 50.392 tons of CO_2eq and gasoline for transportation with 46.443 tons of CO_2eq. The overall scheme of the energy flow can be seen in Appendix 6.

3.2.2. Materials

As a coal production region, it is clear that the main material produced from Muara Enim is coal. According to PTBA, the largest coal company in Muara Enim, approximately 36 million metric tons of coal were extracted from Muara Enim in 2023, with the majority being transported beyond the region for both domestic and international purposes. This continuous flow of coal transportation not only contributes to environmental concerns but also exacerbates traffic congestion in Muara Enim (IESR, 2023). Meanwhile, only around 1 million metric tons are used inside the Muara Enim region as fuel for local coal power plants and local manufacturing. In its operation, coal power plants generate some waste material such as FABA (fly ash and bottom ash) that is normally sold to cement industries. Meanwhile, during the coal extraction, waste material produced, such as rocks, cut-off trees, and construction debris from demolished buildings, are typically disposed of by being dumped back into the mining pit as part of the land reclamation. Apart from the visible materials, concerns arise regarding dust and water contamination. Given the scale of these operations, the environmental impact may persist for a considerable period.

Another notable material flow from Muara Enim comes from the plantation and agricultural production. Though the area is decreasing due to the mining activity, Muara Enim in 2021 managed to produce 177.297 tons of rubber and 45.851 tons of palm oil, which its final product is also exported outside the region. Regarding agricultural products, Muara Enim produces various types of vegetables, fruits, and herbs. However, its production alone is not enough to fulfill the local needs, especially fruit, as most in the market are still imported from other regions. A report from the Department of Fishery of Muara Enim Regency also says that there is a need for around 6.753 tons of fish products in the region. It is quite striking as Muara Enim is famous for its signature dishes made from fish, such as fish cake and smoked fish.

Regarding the output flow in terms of waste, most waste disposal in Muara Enim comes from households and markets in the form of food waste and plastics. In total, Muara Enim produces 148.700 tons of waste material, and in the current system, most of it is simply dumped in a landfill with limited capacity. The government recognizes this as an issue and acknowledges the potential for overcapacity within a six-month period. Therefore, they have started thinking about finding a way to expand the landfill and studying the possibility of building a waste-to-energy facility. Another problem regarding waste is the lack of awareness of waste segregation, making recycling even more challenging. The overall scheme of the material flow can be seen in Appendix 7.

IV. ANALYSIS

The Analysis process started by identifying the potentials provided by the agroforest system and the problem related to the coal mining activity. Intervention strategies then emerged as tools to connect those potentials and problems. Though the interventions resulted from the analysis cover wide aspects from economy to ecology, this research will concentrate on the energy and material components due to their stronger correlation with the spatial aspect and feasibility for calculation.

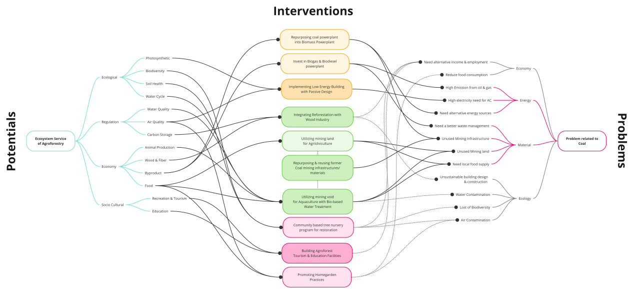

Figure 1. Diagram of the Analysis Process. Source: Author
(The enlarge version can be seen in Appendix 8)

4.1 Future scenario & interventions

4.1.1 Energy

In the future scenario where coal power plants are phased out, the government clearly needs to find another source of energy. One promising alternative closely linked to agroforestry practices is biomass. Biomass is a renewable organic material that comes from plants and animals. It can be burned directly for heat or converted to liquid and gas in the form of biogas and biodiesel. The potential of using biomass as a source of energy is huge in Muara Enim as it has a large plantation area and production forest that can be used for biomass energy sources.

With the incorporation of agroforestry practices, particularly in the utilization of former coal mining areas, the potential for biomass becomes even more compelling. By repurposing these areas for agroforestry, Muara Enim could tap into additional sources of biomass, including agricultural waste and forest by-products. For instance, allocating 5000 hectares of former coal mining land for wooden plantations could yield an estimated supply of approximately 123.008.375 kWh per year or around 40% of their annual electricity consumption. On the other hand, activating the former coal area for food production can also reduce the dependence on imported food products and the need for transportation, ultimately leading to reduced gasoline consumption and emissions.

Regarding infrastructure, biomass has the potential to utilize existing facilities by repurposing former coal installations. The former coal power plant, for example, can be repurposed into a biomass plant with some adjustments and modifications (Casau et al., 2021). Additionally, existing coal train networks can be repurposed for transporting biomass materials and streamlining logistics.

However, due to its typically low power density, which demands a significant amount of land for substantial energy output, biomass alone may face limitations in meeting the increasing energy demands. To address this challenge, combining biomass power plants with other renewable energy generators, such as solar photovoltaic (PV) systems can be a strategic solution. Unlike biomass, solar PV is intermittent but has higher power density and is more flexible in terms of space. By integrating the two sources, it creates a more reliable and balanced energy generation system. Especially looking at the fact that Indonesia has abundant and almost evenly distributed sunlight (IESR, 2021). South Sumatra province, where Muara Enim is located, has the potential for solar energy as much as 17.233 MWp (Manurung et al., 2022).

Another way to balance the energy flow is to reduce the need for energy. For new developments, a low-energy building design that maximizes the use of natural ventilation can reduce the need for AC (which normally consumes most of the household electricity), provided that the dust pollution from coal mining activities no longer exists. Furthermore, land restoration following the coal mining closing and planting greeneries can also help to reduce heat in the microclimate.

4.1.2. Material

The end of coal activity in the future will affect the material flow in the region. For certainty, there will be no more flow of coal product from the region, translating to a reduction in economic activity for Muara Enim. On the other hand, it will leave behind a legacy of unused infrastructure, materials, and open land that holds potential for future development.

Apart from the coal power plant, most of the buildings in Muara Enim are designed to be easily demolished or disassembled. From the storage houses, workshop, TLS to the conveyor belt system. They are mostly made of steel (see Appendix 9). While there is currently no concrete plan for these structures, insights from interviews with the coal mining company suggest two potential courses of action. These structures may either be demolished and dumped into mining pits or be sold in auctions to other mining companies as infrastructure or as materials for recycling.

The other untapped potential from the end of coal mining will be the pioneer trees that were initially planted during the early stages of the restoration process. In current practices, trees like *Acacia mangium,* for example, which have a lifespan of around ten years, are unfortunately left dying as there is no comprehensive strategy from the coal company to manage the forest product. Integration with a wood processing facility will definitely optimize the utilization of this material resource. It will also help prevent the wasteful disposal of cut-off trees during land clearing, often left unused and discarded into mining pits. To further utilize the wood potential in the region, developing a mass timber industry can emerge as a viable solution for tapping into the abundant sources of wood, as well as the region's primary commodity, natural rubber. This strategic initiative has the potential to significantly enhance the overall value of both commodities. Furthermore, the use of natural rubber as the wood adhesive also contributes to the development of sustainable material, as it is renewable, water-based, and has very low or no formaldehyde emission (Hermiati et al., 2013).

The last potential is, of course, the former mining land. Bukit Asam's post-mining land availability is projected to be around 5.200 ha in 2050 (Kontan.co.id, 2021). Some parts of the mining area are located in a dedicated production forest area by the government, meaning it has to be turned back into a forest when the mining activity ends. Apart from that, the other part can be used for other functions, from agriculture to tourism. Understanding the land reclamation process that only uses the early excavated soil reduced by the coal volume to fill back the pit, there will also be a void at the end of the restoration process. This void will naturally be filled with water and eventually become a kind of artificial lake (see Appendix 10).

The implementation of agroforestry in this area will entail better management of the forest area to produce useful wood products and inserting food and agriculture around the forest area to boost productivity. It can also utilize the void for freshwater aquaculture, as demonstrated in the former copper mining pit in Canada and a former gold mining pit in Alta Floresta, Brazil (Otchere et al., 2004), or in a former coal mining pit in Chhattisgarh, India (Kaiser, 2020) (see Appendix 11). Looking back at the current material flow in Muara Enim, this approach will help to fulfill the huge deficit in the production of fish in the area, as stated by the Department of Fishery of Muara Enim Regency. However, careful consideration must be given to the potential contamination of water sources by coal-related activities, leading to elevated levels of metals. To mitigate this, advanced water treatment measures such as natural bioremediation and technological methods using turbines and nanobubbles can be incorporated to ensure environmental and safety standards (Christian et al., 2023).

To support those activities in the future, there will be a need to build various infrastructures to facilitate agroforestry practices, such as processing facilities, wood workshops and factories, and tourism/education facilities. Instead of importing construction material from outside the region, repurposing or ‘mining’ the material from the former coal mining infrastructure to build a new building can be a circular approach that is not only sustainable in principle but also will reduce the need to transport material from outside the region, resulting in the lower carbon footprint.

In the end, with more production of material that will be consumed inside the region, better waste management is also strongly needed, considering it is already become a problem in the current time. Utilizing organic waste to produce biogas and building a waste-to-energy (WtE) facility to process the non-organic waste can be a better solution to prevent problems related to landfills and contribute to the energy production in this area that will lose its coal power plant. Furthermore, the study by SIMEC Atlantis Energy for their conversion project of the Uskmouth power station in Newport, Wales, shows the possibility of repurposing a former coal-fired power station into a WtE plant (Barrett, 2020). Using the current volume of waste, 90.737 tons of organic waste that is produced by households, markets, and other places could be collected and digested to produce biogas enough to substitute the need for the current LPG gas while reducing the emission generated from the gas sector. Meanwhile, with an estimated capability of WtE to generate up to 600 kWh/tons of waste, the current non-organic waste has the potential to be converted into 34.777.951 kWh of electricity in a year. The overall scheme of how the interventions affect the future urban metabolism can be seen in Appendix 12.

V. Conclusion

Examining the current and future condition of Muara Enim using the urban metabolism perspective highlights the significant influence of extensive coal activities on material resources and energy. The halt in coal mining activities will inevitably impact the established urban metabolism, bringing forth challenges but at the same time untapped opportunities.

In terms of energy, coal is the main supply to the electricity in the region, resulting in heightened emissions. Apart from that, the reliance on other fossil fuels in the form of gas and gasoline further contributes to environmental pollution. In the future without coal, agroforestry can bring a potential solution to address energy needs sustainably. The biomass derived from trees planted during restoration efforts can be a valuable alternative. It also offers an opportunity to repurpose existing coal power plants into biomass and WtE plants.

Regarding materials, coal constitutes a significant portion of transported goods within the region, totaling approximately 36 million tons annually, with a substantial portion being utilized outside the region, which contributes to air pollution and traffic jams. Meanwhile, their reported agricultural product stands at approximately 1 million tons, and when we look further at the data and do observations, there is a demand for local food supply, especially fish products. There is also a problem related to waste management as the only municipal landfill grappling to handle the substantial volume of trash, largely originating from households and markets. The implementation of an agroforestry system shows potential for a more productive use of former mining areas. These reclaimed lands could be dedicated to both wooden and agricultural production, while the water bodies can be used for fish farming. Additionally, there is potential to establish a new industry focused on sustainable materials like mass timber / CLT, reducing the dependence on imported building materials and fostering local economic development. The waste material from the increasing agroforest activity can also be utilized to generate biogas. This not only alleviates the pressure on municipal landfills but also addresses the demand for cooking gas while producing lower emissions.

The implication of those regional interventions in the future architectural development and its relevance to other regions facing similar challenges are explained in Appendix 13.

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APPENDIX

Appendix 1. Short History of Coal Activity in Muara Enim

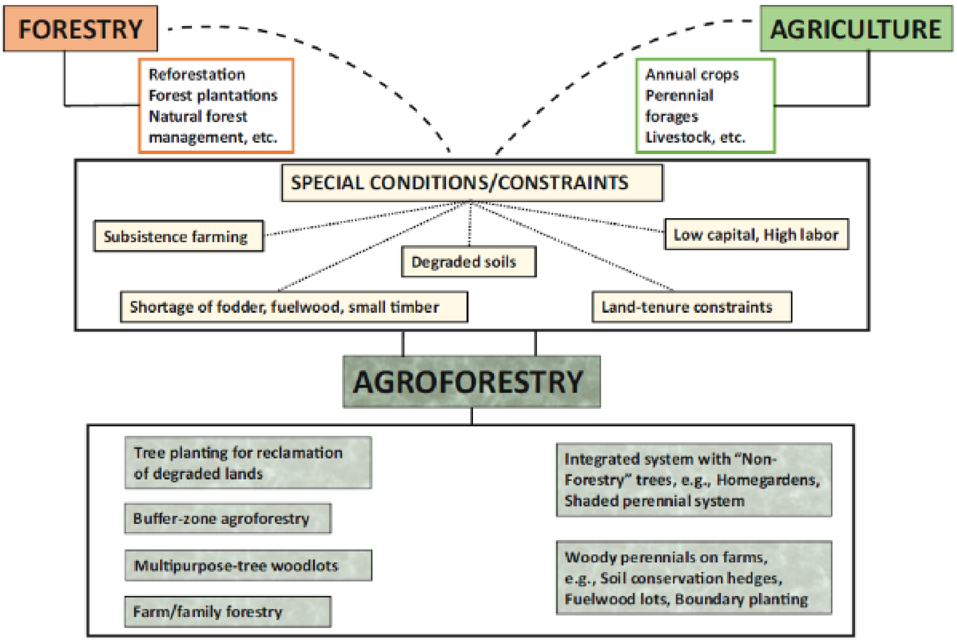
The historical roots of coal mining activity in Muara Enim extend far back into the colonial era when the Dutch exploration discovered a coal resource in Tanjung Enim (an area in Muara Enim) in 1918 and started the mining operation the year after (Suri et al., 2021). As the coal mining activity expanded, the Dutch colonial government then brought in hundreds of workers from Java to use their energy as laborers in the Tanjung Enim. The influence of this large number of migrant workers from Java can be seen in the cultural style of the people of Tanjung Enim decades later.

Fast forward to the Indonesian independence era, the mining operation in Tanjung Enim was acquired by the Indonesian government and turned into a national company called PT Bukit Asam (PTBA). Since then and up to this day, that company has kept expanding its operation with more modern techniques and infrastructure. This generated more economy for the region and slowly turned Tanjung Enim from an agricultural village into a relatively developed city (in some parts, compared to the neighboring regions) with one of the highest incomes in the province.

Appendix 2. Aerial View of Coal Mine in Muara Enim

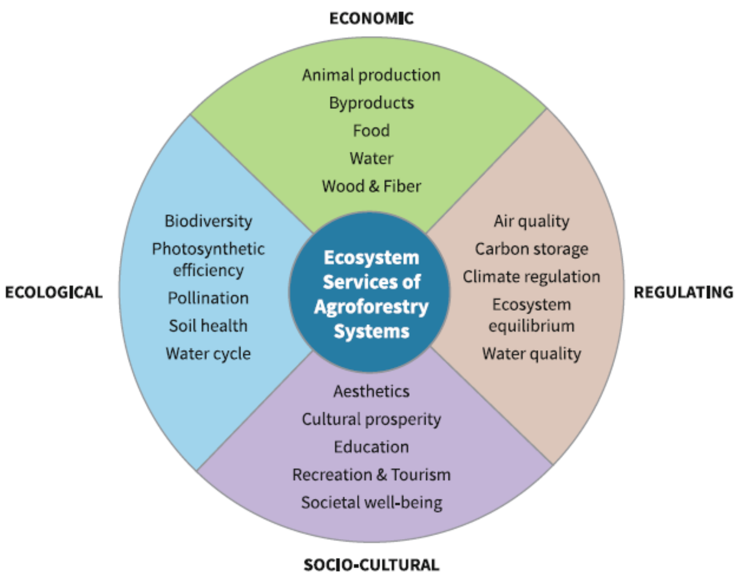
Sources: Esri, DigitalGlobe, GeoEye, i-cubed, USDA FSA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Appendix 3. Agroforestry Concept



Agroforest concept. Source: Nair et al., 2021

Appendix 4. Ecosystem service of Agroforestry



Ecosystem service of Agroforestry. Source: Nair et al., 2021

Appendix 5. Major Tropical Agroforestry Systems and Practices

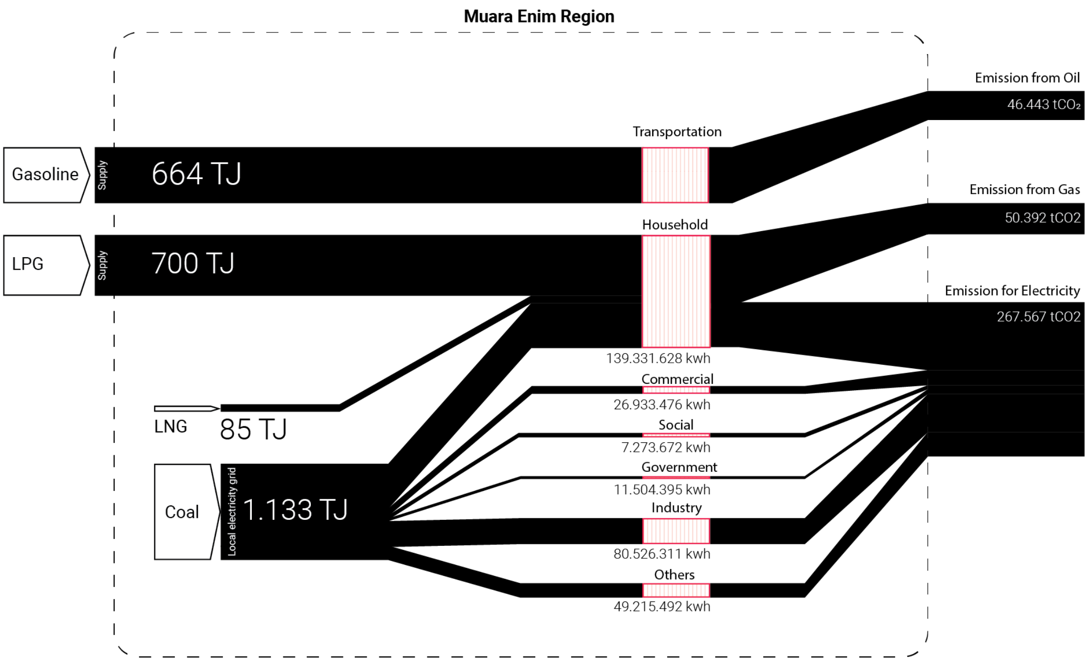
Agroforestry Practice	Brief description (of arrangement of components)	Major groups of components	Agro-ecological adaptability
Agrisilvicultural systems (crops-including shrub/vine/tree crops – and trees)			
(1) Improved fallow	Woody species planted and left to grow during the fallow phase	w: fast-growing preferably leguminous h: common agricultural crops	In shifting cultivation areas
(2) Taungya	Combined stand of woody and agricultural species during early stages of establishment of plantations	w: usually plantation forestry spp. h: common agricultural crops	All ecological regions (where taungya is practiced); several improvements possible
(3) Alley cropping (hedge-row intercropping)	Woody species in hedges; agricultural species in alleys in between hedges; microzonal or strip arrangement	w: fast-growing, leguminous, that coppice vigorously h: common agricultural crops	Subhumid to humid areas with high human population pressure and fragile (productive but easily degradable) soils
(4) Multilayer tree gardens	Multispecies, multilayer dense plant associations with no organized planting arrangements	w: different woody components of varying form and growth habits h: usually absent; shade tolerant ones some-times present	Areas with fertile soils, good availability of labor and high human population pressure
(5) Multipurpose trees on crop lands	Trees scattered haphazardly or according to some systematic patterns on bunds, terraces or plot/field boundaries	w: multipurpose trees and other fruit trees h: common agricultural crops	In all ecological regions esp. in subsistence farming; also commonly integrated with animals
(6) Plantation crop combinations	(i) Integrated multistorey (mixed,dense) mixtures of plantation crops (ii) Mixtures of plantation crops in alternate or other regular arrangement (iii) Shade trees for plantation crops; shade trees scattered (iv) Intercropping with agricultural crops	w: plantation crops like coffee, cacao, coco- nut, etc. and fruit trees, esp. in (i); fuel-wood/fodder spp., esp. in (iii) h: usually present in (iv), and to some ex- tent in (i); shade-tolerant species	In humid lowlands or tropical humid/sui>- humid highlands (depending on the plantation crops concerned); usually in small- holder subsistence system
(7) Homegardens	Intimate, multistorey combination of various trees and crops around homesteads	w: fruit trees predominate; also other woody species, vines. etc. h: shade tolerant agricultural species	In all ecological regions, esp. in areas of high population density
(8) Trees in soil conservation and reclamation	Trees on bunds. terraces, raisers, etc. with or without grass strips; trees for soil reclamation	w: multipurpose and/or fruit trees h: common agricultural species	In sloping areas, esp. in highlands, reclamation of degraded. acid, alkali soils, and sand-dune stabilization
(9) Shelterbelts and wind breaks, live hedges	Trees around farmland/plots	w: combination of tall-growing spreading types h: agricultural crops of the locality	In wind-prone areas
(10) Fuelwood production	Interplanting firewood species on or around agricultural lands	w: firewood species h: agricultural crops of the locality	In all ecological regions
Silvopastoral systems (trees+pasture and/or animals)			
(11) Trees on rangeland or pastures	Trees scattered irregularly or arranged ac- cording to some systematic pattern	w: multipurpose; of fodder value f: present a: present	Extensive grazing areas
(12) Protein banks	Production of protein-rich tree fodder on farm/ rangelands for cut-and-carry fodder production	w: leguminous fodder trees h: present f: present	Usually in areas with high person: land ratio
(13) Plantation crops with pastures and animals	Example: cattle under coconuts in southeast Asia and the South Pacific	w: plantation crops f: present a: present	In areas with less pressure on plantation crop lands
Agrosilvopastoral systems (trees+ crops+ pasture/animals)			
(14) Homegardens involving animals	Intimate, multistorey combination of various trees and crops, and animals around homesteads	w: fruit trees predominate: also other woody species a: present	In all ecological regions with high density of human population
(15) Multipurpose woody hedgerows	Woody hedges for browse, mulch, green manure, soil conservation, etc.	w: fast-growing and coppicing fodder shrubs and trees h: (similar to alley cropping and soil conservation)	Humid to subhumid areas with hilly and sloping terrain
(16) Apiculture with trees	Trees for honey production	w: honey producing (other components may be present)	Depending on the feasibility of apiculture may be present)
(17) Aquaforestry	Trees lining fish ponds, tree leaves being used as 'forage' for fish	w: trees and shrubs preferred by fish (other components may be present)	Lowlands
(18) Multipurpose woodlots	For various purposes (wood, fodder, soil protection, soil reclamation, etc.	w: multipurpose species; special location specific species (other components may be present)	Various

(continued)

Note: w = woody; h = herbaceous; f = fodder for grazing; a = animals

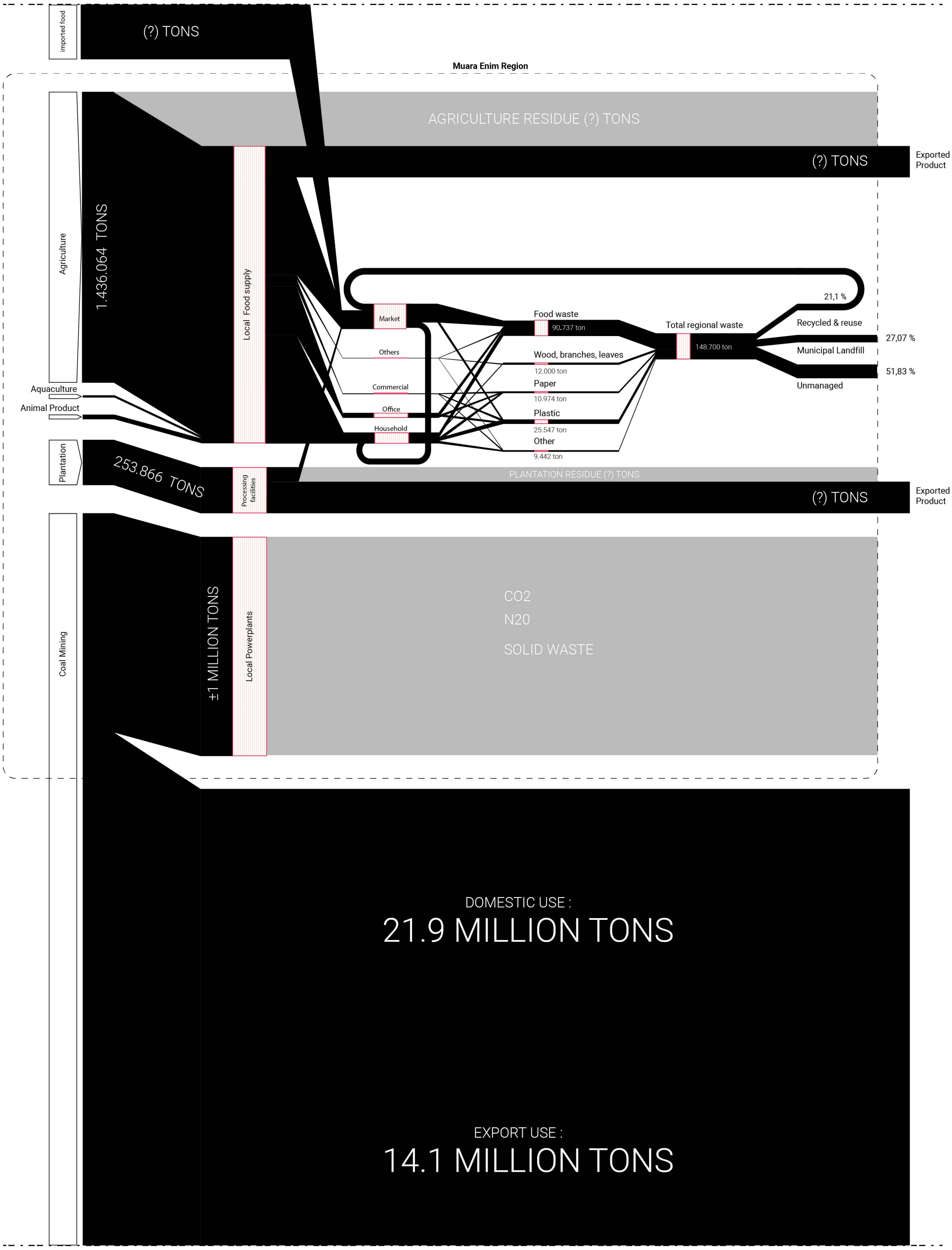
Major Tropical Agroforestry Systems and Practices. Source: Nair et al., 2021

Appendix 6. Current Energy Flow in Muara Enim



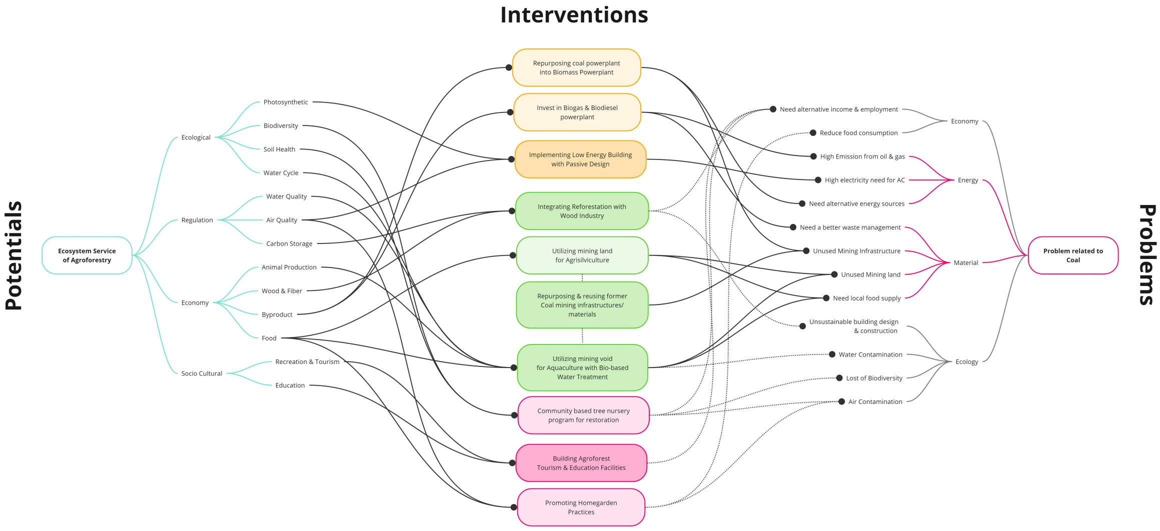
Source: Author

Appendix 7. Current Material Flow in Muara Enim



Source: Author

Appendix 8. Diagram of Analysis Process



Source: Author

Appendix 9. Coal Mining Infrastructures in Bukit Asam's Air Laya mining area.

Conveyor system and Warehouse building.
Source: Author

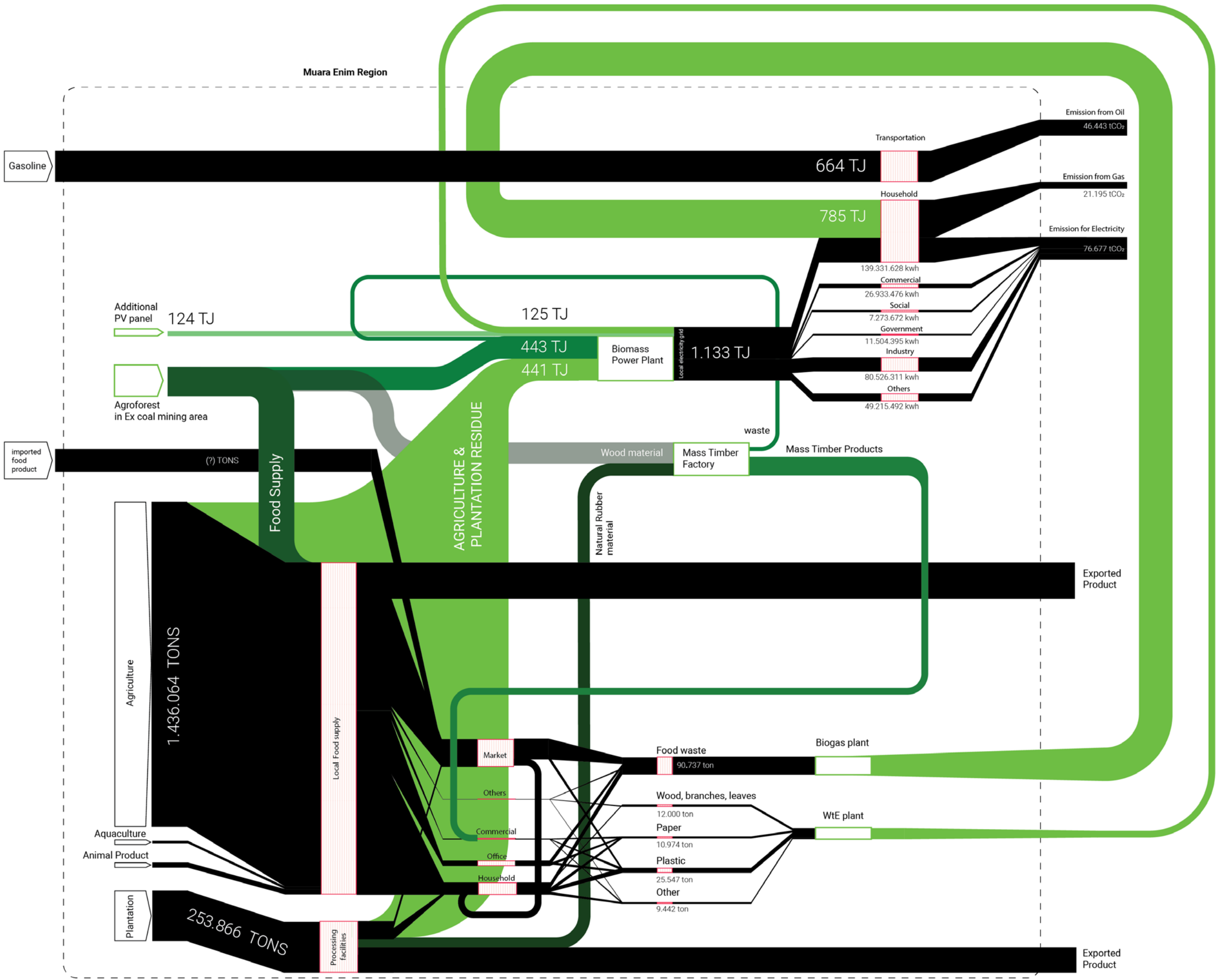
Appendix 10. Image of Void formed in Bukit Asam's Air Laya Mining Area

Source: Author

Appendix 11. Example Of Fish Farm in a Former Coal Mining Pit

An Example of Fish farm in a former coal mining pit in Chhattisgarh, India.
Source: Vivek Gupta, https://science.thewire.in/feature/chattisgarh-mine-closure-jobs-just-transition/

Appendix 12. Agroforest Interventions in Muara Enim Future Urban Metabolism



Source: Author

Appendix 13. Implication to Future Architectural Development

From the analysis of urban metabolism in Muara Enim and the possible interventions that emerged, we can now understand how the agroforestry system can work at the regional level. This insight not only provides practical guidance or policy at the urban scale but also lays the groundwork for establishing an architectural concept that can be used for future development.

The first concept revolves around the energy aspect. Apart from incorporating renewable energy sources such as PV panels in residential buildings or biomass plants in a community context, promoting low-energy design is also important. It can involve several strategies, such as effective cross-ventilation and the integration of greenery and plants to regulate the microclimate.

The second concept is about material use. Agroforestry presents an opportunity to reintroduce wood as the main building material. However, to ensure the responsible and sustainable use of wood, we need to integrate or align the wood selection in the restoration process with its intended use in the construction material. Apart from the wood product from the restoration process, the reuse and repurposing of former coal mining infrastructures can also be incorporated into the material catalog. To do so, further assessment is needed to determine the potential of every material available on the mining site.

The last concept is about the utilization of the former open-pit mining area. As we now know, agroforestry in itself is about increasing productivity and integration; its concept can be implemented in the programming of the former mining area. Its reclamation land has the potential to supply various needs, from agricultural products and wood materials to energy, while its void or water body can be used as a fish farm and supply the fish products in the region. There is also potential to use the area for tourism activity to generate even more economy for the community.

To integrate such activities in a single area clearly requires thoughtful design and well-developed infrastructure, and that is where architecture intervention will be needed the most. Not only to facilitate the agroforestry activity to produce food, energy, and material but also to implement those previous concepts explained above. From promoting low-energy design and incorporating vegetation to (re)using sustainable materials.

Relevance to Other Regions

While this study focuses on the specific case of Muara Enim, a similar approach of introducing agroforestry to substitute coal mining activity can also be applied to other coal-producing regions facing similar challenges. Every open-pit mining activity will leave behind common conditions at the end of its operations, such as degraded lands, voids filled with possibly contaminated water, and unused mining infrastructures. There is also a standard process of restoration and revegetation that is supposed to be implemented in every mining closure. Those typical conditions can be the starting points for architects in visioning architectural interventions in soon-to-be-closed coal mining regions.

However, it is understandable that each region may have different key issues and potentials beyond the mining border. Therefore, any interventions must be designed and structured according to their local condition (Stremke et al., 2022). People in different regions may also have different needs and aspirations for their future. For instance, the idea of utilizing mining voids for aquaculture in developing countries might be driven by the need for food supply and employment, while in developed countries, it could be more focused on recreational fishery (Otchere et al., 2004).

In addition to a close examination of culture and social conditions, analyzing urban metabolism using Material Flow Analysis as a method can help to map and visualize future problems and potentials in the region. Some regions may lack sufficient forested areas but have the potential for wind energy or geothermal sources that can substitute coal energy. Other regions might not face issues with food supply but urgently require space for solar panels. This comprehensive understanding of local conditions is essential to create contextual interventions, ensuring they address genuine future needs with local potentials without overburdening existing resources. In the end, it will make way for a future architecture project that is well integrated with its context, sources, and users.

Appendix 14. Data Collections and Calculation

Demography		Value		Source / Explanation
	Population of Muara Enim (2021)	593 300	people	https://muaraenimkab.bps.go.id/indicator/12/77/1/jumlah-penduduk.html
	Household in Muara Enim (2020)	154 558	households	https://okukab.bps.go.id/indicator/12/426/1/jumlah-rumah-tangga-menurut-kabupaten.html

Energy		Value		Source / Explanation
Electricity	Total electricity consumption	314.784.973,20	kWh/year	Projection from : Data Rekap/ Total TUL III-09 Penjualan Tenaga Listrik PLN ULP Muara Enim 2023
	Total electricity consumption Social	7.273.671,60	kWh/year	Projection from : Data Rekap/ Total TUL III-09 Penjualan Tenaga Listrik PLN ULP Muara Enim 2023
	Total electricity consumption Households	139.331.628,00	kWh/year	Projection from : Data Rekap/ Total TUL III-09 Penjualan Tenaga Listrik PLN ULP Muara Enim 2023
	Total electricity consumption Commercial	26.933.475,60	kWh/year	Projection from : Data Rekap/ Total TUL III-09 Penjualan Tenaga Listrik PLN ULP Muara Enim 2023
	Total electricity consumption Industry	80.526.310,80	kWh/year	Projection from : Data Rekap/ Total TUL III-09 Penjualan Tenaga Listrik PLN ULP Muara Enim 2023
	Total electricity consumption Government	11.504.395,20	kWh/year	Projection from : Data Rekap/ Total TUL III-09 Penjualan Tenaga Listrik PLN ULP Muara Enim 2023
	Total electricity consumption Others	49.215.492,00	kWh/year	Projection from : Data Rekap/ Total TUL III-09 Penjualan Tenaga Listrik PLN ULP Muara Enim 2023
	Conversion of 314.784.973 kWh electricity to TJ	1.133,23	TJ	https://www.convertunits.com/from/kWh/to/terajoule
	Emission from 314.784.973 kWh electricity from coal	267.567,23	tCO2eq	1 MWh from coal fired plant = 850 kg CO_2, https://www.eeagrants.gov.pt/media/2776/conversion-guidelines.pdf
Gasoline	Supply of Gasoline	19.416,00	kl/year	https://pertamina.com/id/Kuota-Dan-Realisasi-Premium-Pertamina-per-Kota-Kabupaten-Tahun-2021-Update-September-2021
	Conversion of 19416 kl gasoline to TJ	664,03	TJ	https://hextobinary.com/unit/energy/from/gasoline/to/terajoule
	Emission from 19416 kl gasoline	46.443,07	CO2eq	1 litre gasoline = 2,392 kg CO_2 (https://www.eeagrants.gov.pt/media/2776/conversion-guidelines.pdf)
Gas	Supply of LPG	15.220,00	metric tons/year	Andi Hartono, Kabid Perdagangan Dinas Perindustrian dan Perdagangan Pemkab Muara Enim (https://sumeks.disway.id/read/405528/muara-enim-dapat-penambahan-kuota-1522-metrik-ton)
	Conversion of 15.220 metric ton to TJ	700,12	TJ	The specific calorific value of LPG is around 46 MJ/kg. www.energypedia.info
	Emission from 15.220 metric ton LPG	45.812,20	tCO2eq	1kg LPG produces 3,01 kg CO_2 (https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html#gsc.tab=0)
	Supply of Natural gas	2.410.668,00	m3/year	15453 gas networks connected in Muara Enim (STATISTICS Oil and Gas Semester I 2022) Estimation for household gas consumsion = 13m3 per month
	Conversion of 2.410.668 m3 to TJ	84,78	TJ	1 TJ (Terajoule) = 28433 m3 LNG. (https://www.cbs.nl/en-gb/figures/detail/85666ENG#shortTableDescription)
	Emission from 2.410.668 m3 natural gas	4.580,27	tCO2eq	1 m3 natural gas = 1,9 kg CO_2 (https://www.eeagrants.gov.pt/media/2776/conversion-guidelines.pdf)
	Total emission from LPG & Natural gas	50.392,47	tCO2eq	45.812,20 + 4.580,27

Material		Value		Source / Explanation
Coal	Total Coal Production	36.098.699,68	metric tons/year	Rencana dan Realisasi Penjualan Tahun 2023 dan Rencana Tahun 2024-2026 PT.Bukit Asam
	Coal used for Muara Enim PLTU	1.000.000,00	metric tons/year	Estimation. Interview with PT. Bukit Asam Staff
	Coal for Domestic use	21.926.486,77	metric tons/year	Rencana dan Realisasi Penjualan Tahun 2023 dan Rencana Tahun 2024-2026 PT.Bukit Asam
	Coal for Export	14.172.212,90	metric tons/year	Rencana dan Realisasi Penjualan Tahun 2023 dan Rencana Tahun 2024-2026 PT.Bukit Asam
Agriculture	Seasonal Vegetation Production	293.116,40	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Medicine Plants Production	71.673,20	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Annual Fruits & Vegetables Production	839.344,10	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Crops Production	34.859,84	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Rice Production	197.070,78	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	In total	1.436.064,32	tons/year	
Aquaculture	Fish production	11.668,27	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Fish consumption	18.421,03	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
Animal Product	Meat Production	10.718,64	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Eggs	14.615,64	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
Plantation / Estate crops	Rubber Production	177.297,00	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Oil Palm Production	45.851,00	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Coffee Production	29.176,00	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Coconut Production	1.278,00	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	Cacao Production	264,50	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
	In total	253.866,50	tons/year	collected from : MUARA ENIM REGENCY IN FIGURES 2023
Waste	Total Annual Waste	148699,98	tons/year	Neraca Pengelolaan Sampah Tahun 2022-2023 Kabupaten Muara Enim
	Food waste	90.736,73	tons/year	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Paper waste	10.974,06	tons/year	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Wood, branches, leaves	12.000,09	tons/year	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Plastic	25.546,66	tons/year	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Others	9.442,45	tons/year	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Waste from household	66,88	tons/day	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Waste from market	53,94	tons/day	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Waste from office area	23,76	tons/day	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Waste from commercial area	3,88	tons/day	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Waste from other	0,23	tons/day	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Recycled / reused waste	21,1	%	Neraca Pengelolaan Sampah Tahun 2022-2023 Kabupaten Muara Enim
	Goes to Landfill	27,07	%	Neraca Pengelolaan Sampah Tahun 2022-2023 Kabupaten Muara Enim
	Unidentified	51,83		Neraca Pengelolaan Sampah Tahun 2022-2023 Kabupaten Muara Enim

System Intervention		Value		Source / Explanation
Biomass	Estimated Biomass energy from 5.000ha Acasia Mangium	123.008.375,00	kWh	Calorific Value 20,083 kj/kg. Usable waste percentage 100% . Source : IESR (2021). Beyond 443 GW: Indonesia's infinite renewable energy potentials. Institute for Essential Services Reform.
	Estimated Biomass energy from 45.851 tons Palm oil production	75.761.899,85	kWh	Calorific Value 23,605 kj/kg. Usable waste percentage 40% . Source : IESR (2021). Beyond 443 GW: Indonesia's infinite renewable energy potentials. Institute for Essential Services Reform.
	Estimated Biomass energy from 29.176 tons coffee production	46.820.186,00	kWh	Calorific Value 18,340 kj/kg. Usable waste percentage 50% . Source : IESR (2021). Beyond 443 GW: Indonesia's infinite renewable energy potentials. Institute for Essential Services Reform.
	Total Biomass energy	245.590.460,85	kWh	
	Conversion of 245.590.460,85 kWh electricity to TJ	884,13	TJ	Consist of 442,83 TJ from Acasia Mangium forest in former mining area and 441,30 TJ from Palm oil & Coffee production. (https://www.convertunits.com/from/kWh/to/terajoule)
	Emission from 245.590.460,85 kWh Biomass Electricity	56.485,81	tCO2eq	Biogass produces 230 gCO2 /kWh (https://www.world-nuclear.org/information-library/energy-and-the-environment/carbon-dioxide-emissions-from-electricity.aspx)
WtE	Unorganic Waste Production	57.963,25	tons/year	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Energy Produced from incinerating 57963,25 tons of waste	34.777.951,32	kWh	The typical range of net electrical energy that can be produced is about 500 to 600 kWh of per tonne of waste incinerated. (https://sustainable.org.za/userfiles/incineration(1).pdf)
	Conversion of 34.777.951,32 kWh to TJ	125,20	TJ	(www.convertunits.com/from/kWh/to/terajoule)
	Emission from 34.777.951,32 kWh Electricity form Waste material	18.780,09	tCO2eq	The carbon intensity of European incinerators is 540gr CO2/kWh (https://ukwin.org.uk/files/pdf/UKWIN-2018-Incineration-Climate-Change-Report.pdf)
Solar PV	Additional Electricity supply to fullfil annual Electricity use	34.416.666,67	kWh	Capacity factor 16% (https://www.mckinsey.com/id/our-insights/how-to-power-indonesias-solar-pv-growth-opportunities)
	Area needed for Solar PV	143,74	ha	Around 9m2 per households in Muara Enim
	Conversion of 34.416.666,67 kWh to TJ	123.90	TJ	(www.convertunits.com/from/kWh/to/terajoule)
	Emission from 34.416.666,67 kWh	1.411,08	tCO2eq	Solar PV produces 41 gCO2 /kWh (https://www.world-nuclear.org/information-library/energy-and-the-environment/carbon-dioxide-emissions-from-electricity.aspx)
Biogas	Organic Waste Production	90.736,73	tons/year	Data Komposisi dan Sumber Sampah. Dinas Linkungan Hidup Kabupaten Muara Enim
	Potential Biogas generated from 90736,73 tons organic waste	22.684.181,95	m3	the amount of biogas production is from 70 to 250 cubic meters per ton of waste. (https://www.sciencedirect.com/science/article/pii/S2666154323001758)
	Conversion from 22.684.181,95 m3 gas to TJ	840,81	TJ	1 cubic metre (m3) = 35.301 cubic feet @ 14.73 psia and 60F, million cubic feet (MMcf) = 1.05 TJ (https://www.cetinerengineering.com/conversiontables.html)
	Annual gas supply needed	785	TJ	From the current supply of Natural Gas and LPG in Muara Enim
	Emission from 785 TJ Biogas	21.195,00	tCO2eq	A conventional biogas plant produces 27 grams CO2 per MJ (https://www.europeanbiogas.eu/9611/)

Table of Data Collections Source: Author

Type	Equation for calculating technical potential	Explanation of each variables
Solar	$Cap_{PV} = A \cdot PD$ $E_{PV} = Cap_{PV} \cdot PVOUT \cdot 365 \cdot 1/1000$	Cap_{PV} is the technical capacity in GWp, A is the suitable coverage in km², PD is power density (0.041 GWp/km² for PV according to NREL, 2013b), E_{PV} is the technical generation in GWh, and $PVOUT$ is an daily average of estimated power generated by PV per 1 kWp, or well-known as capacity factor
Biomass	$Prod = A \cdot \beta \cdot \gamma$ $Cap_{biomass} = Prod \cdot \alpha \cdot \eta \cdot \vartheta$ $E_{biomass} = Cap_{biomass} \cdot CF$	$Prod$ is total production in each area (ton), A is the area (m²), β is the production per m² for each plant, γ is the harvested cycle per year, $Cap_{biomass}$ is the generated power from biomass power plant (kW), α is the calorific value (kJ/kg), η is the power plant efficiency assumed to be 25%, and ϑ is the percentage of wastes from the whole fruit or crop. β, γ, and ϑ are detailed in Table 5 and 6. $E_{biomass}$ is the generated power (kWh/year) and CF is capacity factor that can assumed to be 70%.

Commodity	Type of waste	Calorific value per kg		Waste percentage per kg	
		Calorific value (kJ/kg)	Source	Waste percentage (%)	Source
Coffee	Husk	18,340	Miito & Banadda (2017)	50	Oliveira & Franca (2015)
Paddy	Husk	12,980	Ozturk & Bascetincelik (2006)	20	Singh (2018)
Palm	Kernel	23,605	Paul et al. (2015)	40	Koura et al. (2016)
	Fiber	14,512		11.5	
	Empty fruit bunch	17,400		25.5	
Acacia	Wood	20,083	Private archive of GGGI	100	Private archive of GGG

Technical Potential Calculation and Detailed Calorific Value and Waste Percentage for Each Commodity. Source: IESR 2021