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SCALING UP BIOMASS FOR THE ENERGY TRANSITION

UNTAPPED OPPORTUNITIES IN SOUTHEAST ASIA

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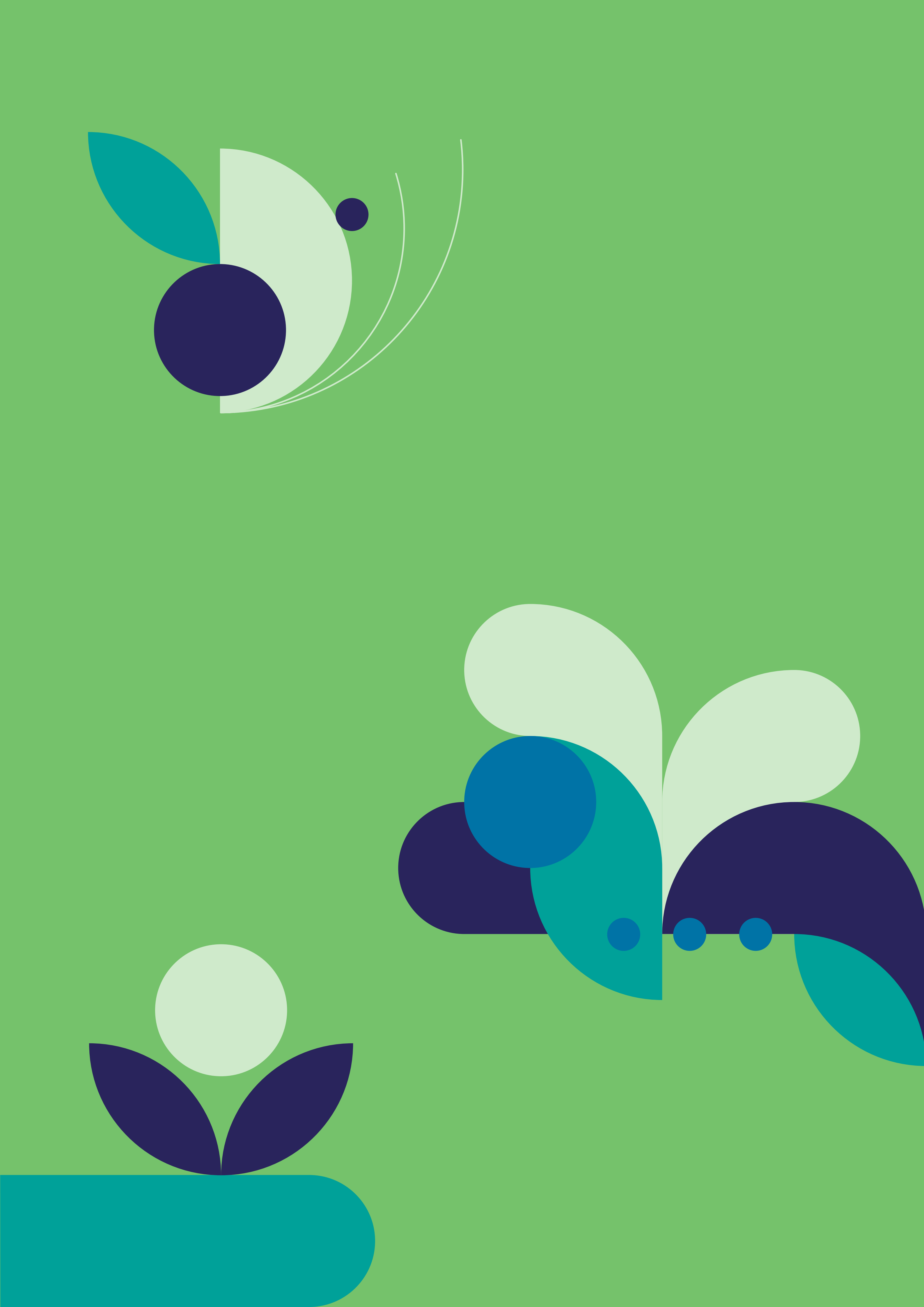

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ABBREVIATIONS

ADB	Asian Development Bank
AEDP	Alternative Energy Development Plan
APAEC	ASEAN Plan of Action for Energy Cooperation
ASEAN	Association of Southeast Asian Nations
BCR	benefit–cost ratio
BOD	biochemical oxygen demand
CAPEX	capital expenditure
CFPP	Compensatory Forest Plantation Programme
CHP	combined heat and power
CO_2	carbon dioxide
COD	chemical oxygen demand
EFB	empty fruit bunch
EJ	exajoule
ENPV	economic net present value
ESG	environmental, social and corporate governance
FAO	UN Food and Agriculture Organization
FFB	fresh fruit bunch
GDP	gross domestic product
GHG	greenhouse gas
GJ	gigajoule
GTFS	green technology financing scheme
GW	gigawatt
IC	internal circulation (reactor)
ICAO	International Civil Aviation Organization
IEA	International Energy Agency
IFC	International Finance Corporation
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
ISPO	Indonesian Sustainable Palm Oil
ITA	Investment Tax Allowance
JIRCAS	Japan International Research Center for Agricultural Sciences
kWh	kilowatt hour
MBIPV	Malaysia Building-Integrated Photovoltaic Project
mbpd	million barrels per day
MIDA	Malaysian Investment Development Authority
MOIT	Ministry of Industry and Trade
MPOB	Malaysian Palm Oil Board
MSPO	Malaysian Palm Oil
MW	megawatt

NBS	National Biomass Strategy (Malaysia)
NDC	Nationally Determined Contribution
NPV	net present value
OECD	Organisation for Economic Co-operation and Development
OPEX	operating expenditure
OPF	oil palm frond
OPT	oil palm trunk
PDP	Power Development Plan (Thailand)
PES	primary energy supply
PESTEL&F	political, economic, social, technical, environmental, legal and financing
PJ	petajoule
PKS	palm kernel shells
POME	palm oil mill effluent
PPA	power purchase agreement
PV	(solar) photovoltaic
RDF	refuse derived fuel
REBF	Renewable Energy Business Fund
REDD	reducing emissions from deforestation and forest degradation
RM	Malaysian ringgit
RSB	Roundtable on Sustainable Biofuels
RSPO	Roundtable on Sustainable Palm Oil
SEDA	Sustainable Energy Development Authority (Malaysia)
SREP	Small Renewable Energy Power (Malaysia)
SS	suspended solids
tCO_2e	tonnes of carbon dioxide equivalent
TES	total energy supply
TFEC	total final energy consumption
toe	tonne of oil equivalent
TPES	total primary energy supply
UN	United Nations
UNFCCC	UN Framework Convention on Climate Change
USD	US dollars
USDA	US Department of Agriculture
WBG	World Bank Group
WHRPG	Waste Heat Recovery Power Generation (project, Indonesia)

EXECUTIVE SUMMARY

As one of the fastest growing regions in the world in terms of gross domestic product (GDP), population, and demand for both food and energy, Southeast Asia has a strong need to decarbonise its economies and modernise its energy systems. In 2018, around 75% of primary energy demand in the region was met by fossil fuels such as oil, coal and gas.

Many key economic activities depend on fossil fuels for heat, which makes substitution with established forms of renewable energy such as hydro, solar or wind challenging. Bioenergy is the most versatile form of renewable energy derived from forestry and agricultural products including residues and wastes.

IRENA's Global Renewables Outlook: Energy Transformation 2050 (IRENA, 2020a) reported that bioenergy could become the largest energy source in the total energy mix in Southeast Asia, accounting for over 40% of total primary energy supply (TPES) in 2050 under its Transforming Energy Scenario (TES), which is consistent with the Paris Agreement's goal of restricting global temperature rises to well below 2°C. In this scenario, the majority of the biomass would be used in the industry (40% of total bioenergy supply) and transport sectors (37% of total bioenergy supply).

This report investigates the potential for bioenergy to economically replace a portion of fossil fuel use in the energy markets of five Southeast Asian countries. It outlines the need for a robust bioenergy transformation plan to reduce dependency on fossil fuels, strengthen national resilience and enhance energy security. The key barriers and interventions identified in this study may therefore serve as a guide for the policy actions required to develop such a plan.

Sustainable bioenergy pathways

Whilst all renewable energy sources have a role to play in Southeast Asia's energy transition, this report focuses on the potential for bioenergy to serve Southeast Asia's energy demand by identifying 13 sustainable bioenergy pathways that will enable bioenergy to compete economically with fossil fuels in the region's energy markets.

The analysis demonstrates an abundance of untapped bioenergy in Southeast Asia, with at least 7.1 exajoules (EJ) of selected feedstock per year by 2050 in the five countries studied.[1] It also identifies immediate opportunities for adopting bioenergy in Southeast Asia's energy markets, demonstrating the potential over the medium- and long-term horizons for the selected sustainable biomass to economically meet 2.8 EJ of the energy demand by 2050.

The economic costs and benefits of an energy market transition to sustainable biomass have been appraised for the 13 potential pathways, revealing potential benefits of USD 144 billion of net present value of socio-economic benefits in 2050, creating over 452 000 new resilient jobs and saving around 442 million CO_2e tonnes of greenhouse gases (GHG) emission per year.

TABLE 1: Summary of 13 potential pathways across five countries

Type of feedstock	Type of process	Total applicable potential bioenergy equilibrium (2050)
Agricultural residues from major crops, rubber and acacia	Direct combustion for industrial heat generation	696 PJ
	Direct combustion for combined heat and power generation	1065 PJ
Palm oil mill effluent (POME) and cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and combined heat and power (CHP) plants	32 PJ
Agricultural residues from major crops, rubber and teak	Direct combustion for industrial heat generation	8 PJ
	Direct combustion for combined heat and power generation	449 PJ
Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants	6 PJ
Sugarcane molasses and cassava starch and chips to bioethanol	Fermentation & blend to produce bioethanol	98 PJ
Agricultural residues from major crops, rubber and eucalyptus	Direct combustion for industrial heat generation	188 PJ
	Direct combustion for combined heat and power generation	145 PJ
Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants	4 PJ
Sugarcane molasses to bioethanol	Fermentation & blend to produce bioethanol	4 PJ
Acacia and rubber	Direct combustion in CHP for heat and power generation	106 PJ
Woody residues	Direct combustion for industrial heat generation	17 PJ

Note: PJ = Petajoules

1 The total bioenergy potential is higher in the region (IEA, 2019; IRENA, 2017a; Junginger, Koppejan and Goh, 2020) and IRENA analysis estimated that bioenergy potential from agricultural residues, closing yield gap, reduced wastes and productive forests, would reach over 14 EJ by 2050 in Indonesia, Malaysia, Vietnam, Thailand and Vietnam (IRENA, 2017a)

Sustainable bioenergy pathways must link demand in energy markets with secure bioenergy supplies. There are four key market "push and pull" factors that decision makers must consider in this regard: availability, sustainability, accessibility and market.

AVAILABILITY

There is an abundance of untapped bioenergy in Southeast Asia. Decision makers can create frameworks that offer robust bioenergy supply pathways, building confidence among private financiers.

The high productivity of Southeast Asia's agriculture sector generates considerable volumes of under-utilised residues. The table below provides estimated volumes for sustainable bioenergy by feedstock in 2050 in Indonesia, Malaysia, Myanmar, Thailand and Vietnam. These ASEAN member countries were chosen as target countries for this study due to their large agricultural industries and subsequent potential in terms of untapped biomass feedstock.

TABLE 2: Estimated availability of selected biomass energy resources

Country	Feedstock	Quantity available by 2050 (million tonnes)
Indonesia	Agricultural residues (palm oil, rice and sugarcane)	197.4
	Rubber	13.7
	Acacia	5.0
	Palm oil mill effluent (POME)	78.8
	Cassava pulp	10.0
Thailand	Agricultural residues (sugarcane, rice and palm oil)	63.7
	Rubber	7.1
	Teak	1.9
	Cassava pulp	9.0
	Sugarcane molasses	7.9 (ethanol: 2.0 billion litres)
	Cassava roots and starch	25.4 (ethanol: 4.8 billion litres)
Vietnam	Agricultural residues (rice, sugarcane and maize)	37.5
	Rubber	2.0
	Eucalyptus	1.1
	Cassava pulp	4.8
	Sugarcane molasses	0.9 (ethanol: 0.2 billion litre)
Malaysia	Acacia	6.3
	Rubber	5.2
Myanmar	Woody residues	1.9

Private financiers of renewable energy projects often cite security of bioenergy supply as one of the biggest obstacles to investing in bioenergy projects. There are various factors that determine the total available volumes of bioenergy, including biomass scalability and seasonality.

One way that governments can mitigate the seasonality of biomass outputs this is by forming a central collection agency to map the collection of residuals from various agricultural practices and crops throughout the year and distribute them systematically according to demand.

SUSTAINABILITY

Decision makers can strengthen sustainability stewardship practices through institutional and industrial capacity building to increase the resilience, availability and security of supply, whilst also enhancing the attractiveness of the sector to private financiers, especially those using ESG investment criteria.[2]

The socio-economic benefits derived from increased biofuel consumption can be improved by implementing sustainable activities throughout the supply chain, from production through to supply and consumption. If appropriate policies are implemented to provide long-term support throughout the supply chain, sustainable bioenergy can meet global food needs and climate goals as well as promote economic activities, create jobs, enrich the land and improve livelihoods (Souza et al., 2017) investments in technology, rural extension, and innovations that build capacity and infrastructure, promotion of stable prices to incentivise local production and use of double cropping and flex crops (plants grown for both food and non-food markets).

Sustainable bioenergy has been successfully pioneered in Europe and the United States, where these issues have been addressed through:

- diligent stewardship to ensure that bioenergy is sustainably sourced;
- initial sourcing of biomass from agri-industry process residues before expansion to include sourcing from agricultural residues;
- aggregating biomass feedstocks to mitigate quality and volume risks from factors such as seasonal variations, changes in agricultural crops etc.; and
- use of fuel enrichment technologies to provide consistent quality of bioenergy fuel with a calorific value that represents a viable alternative to fossil fuels.

As this study is concerned with biomass feedstocks that can be produced sustainably, the identification and analysis of bioenergy pathways is based on the principles that

2 ESG investment criteria include: environmental (resource use, emission, innovation); social (workforce, human rights, community, product responsibility); and governance (management, shareholders, Corporate social responsibility (CSR) strategy) considerations.

1) no land use change associated with bioenergy feedstock production is anticipated and 2) that the demand for food and feed is not distorted by bioenergy feedstock production, despite population increases.

Environmental and social (E&S) factors must also be considered when evaluating biomass feedstock feasibility and costs for the respective bioenergy pathways, as detrimental E&S impacts can significantly impede implementation and raise reputational risks.

ACCESSIBILITY

Decision makers can identify accessible biomass feedstocks in the short-term to demonstrate the viability of this source for energy markets, before moving on to address political, legal, social and environmental concerns. Infrastructure construction to increase biomass accessibility in the medium and long terms will directly impact the scalability of feedstock and deliver socio-economic benefits.

Volumes of accessible bioenergy resources will grow over time with increased market awareness, improved logistics chains, technology enhancements and mounting private financing appetite.

Private financiers of renewable energy projects typically have a negative view of bioenergy supply, but this is often due to out-dated perceptions on issues that now have a range of commercially proven technical solutions. There is, therefore, an urgent need to build awareness amongst decision makers of commercially proven technical solutions.

Based on a number of key lessons drawn from successful projects in established markets, decision makers in Southeast Asia should seek to:

- explore how agricultural and industrial sectors can collaborate to establish supply and logistics networks for creating secure and sustainable biomass supplies;
- determine which fuel enrichment technologies would be appropriate for the sustainable bioenergy resources available and would meet the specifications of local energy markets;
- identify knowledge and technology gaps that require further R&D and pilot projects to test the "first-of-a-kind" risks of deploying such technologies in Southeast Asia's markets; and
- form ministerial level collaboration to unlock further opportunities and ensure the smooth execution of bioenergy strategies in each country.

Decision makers can also accelerate the adoption of sustainable biomass by addressing negative sentiment among private financiers. This can be achieved by demonstrating the commercial successes achieved in markets that have advanced the deployment of sustainable bioenergy.

MARKET

Decision makers can model and monitor energy markets to effectively manage the stimulation of pull factors over short, medium and long-term planning horizons and determine an appropriate, substitutable market.

For bioenergy to compete economically with fossil fuels in energy markets, sustainable bioenergy pathways must link demand with secure bioenergy supplies. Sustainable bioenergy has limited access to energy markets due to technology constraints in many sectors. Immediate demand can be found where existing facilities, plants and equipment can use blends of biofuels with fossil fuels, while research, development and piloting will be necessary to increase accessibility. To create demand will then require private financiers to invest in facilities, plant and equipment that bring revenues into new sustainable bioenergy supply chains.

Decision makers can facilitate transitions in the energy markets by regulating the requirement for industrial, commercial and domestic users to progressively reduce fossil fuel reliance, seek greater efficiency in facilities, plants and equipment, and progressively increase the proportion of sustainable bioenergy. They can also:

- influence energy market dynamics by increasing taxation on fossil fuels, whilst reducing the tax burdens on sustainable biomass;
- give tax incentives for R&D and investments in new facilities, plants and equipment that are fuelled by sustainable bioenergy; and
- provide feed-in-tariffs to incentivise private sector participation in the market (which is proven in Southeast Asia and elsewhere). However, careful design needs to be considered to ensure the right level of incentive while not adding too much burden to the energy off-takers or government fiscal support.

Key market barriers to a vibrant sustainable bioenergy market

The study analysed the enabling framework of each country to identify the key market barriers – and subsequent interventions – required to form a sustainable bioenergy market. These include the following:

INDONESIA

- **Low policy incentive to decarbonise industrial process heat.** Indonesia can seek to create more incentives for private companies to retrofit their facilities with commercially viable technology that will allow existing plants to use biomass feedstock for the heat generation process. Agricultural residue from major crops is identified as a potential feedstock. Mobilising palm oil residues and waste such as Empty Fruit Bunch (EFB), Palm Kernel Shells (PKS), old trunks and POME for bioenergy feedstock will not only reduce GHG emissions but also boost the overall sustainability of the oil palm industry.

- **Higher cost of converting solid biofuels to energy compared with coal.** Production of commercially viable solid biofuels conversion will facilitate uptake of this bioenergy pathway. Fossil fuel subsidies in Indonesia, which lower fossil fuel costs, make solid biofuel feedstock less attractive. To increase commercial viability and reduce cost of producing solid biofuels, the Indonesia government can introduce a favourable regulatory framework; remove subsidies for fossil fuels; and increase spending on R&D to further reduce the cost of conversion from biomass to energy.

THAILAND

- **Lack of R&D initiatives to sustainably improve the yield of Thai agricultural products.** For each bioenergy pathway to succeed, and to allay sustainable and environmental concerns when production is scaled, Thailand's agricultural crop yields – and, subsequently, agricultural residue production – must improve. The government can incentivise investment in R&D to help Thai farmers improve their farming techniques, processes and tools, and establish programmes to facilitate this improvement.

- **Public perceptions of bioenergy.** As with the region in general, the socio-economic benefits of bioenergy consumption are not commonly known in Thailand. Nurturing positive public perceptions of bioenergy as a sustainable source of energy, whilst providing information on how any negative impacts are mitigated, could shift public opinion toward bioenergy as a primary energy source, even if prices are higher than for traditional fossil fuels. This could be achieved though government marketing campaigns and other programmes to increase public awareness of bioenergy.

VIETNAM

- **Economic feasibility of applying the technologies required to convert biomass feedstock to bioenergy.** It could be difficult to introduce new technology to the Vietnam market owing to the high capital costs and lack of government subsidies or incentives. Although the Ministry of Industry and Trade (MOIT) increased the feed-in-tariff to US cents 7.03 per kilowatt hour for combined heat and power biomass plants in 2020, it remains unattractive to investors. Investment in advanced energy technologies may not be a strategy priority in lieu of other goals such as improving education, reducing poverty and the ensuring the financial stability of public services. Furthermore, fuel supply is difficult to control, given the lack of stability and sustainability of feedstock, and its seasonal price changes.

- **Institutional barriers.** incentive programmes for investments in green energy, including bioenergy feature provisions for priority credit, enterprise tax reduction, land rent reduction, and a power purchase agreement (PPA). However, incentives have not been effectively implemented – particularly in rural areas – and there is no effective focal point in the government system to co-ordinate these efforts. Also, bioenergy-friendly policies are undermined by a lack of co-ordination and a lack of adequate investigation of factors including potential, demand and usage.

MALAYSIA

- **Lack of agreement between policy makers and departments.** A key barrier for the Malaysian government in reaching the proposed renewable energy targets is the lack of agreement between policy makers and ministries (Kardooni, Yusoff and Kari, 2015). At least seven major ministries were involved in renewable energy planning in the 9th Malaysia Plan (2006–2010), each with equal responsibilities; yet stronger communication is required to avoid unco-ordinated efforts towards shared goals.

MYANMAR

- **Lack of preferential regulatory framework for the bioenergy transition**. Myanmar has an immature legal and regulatory framework for renewable energy as a whole and policy in the context of the energy transition lacks a co-ordinated approach. While universal access to electricity will be the priority in the energy policy agenda of Myanmar, the country should adopt a holistic approach to 1) modernise the energy system based on renewables; 2) phase out the traditional use of wood fuels whilst expanding rural electrification; and 3) halt deforestation and forest degradation by mitigating the pressure on forest resource exploitation and improving the efficiency of woody biomass utilisation. The development of a bioenergy transition masterplan with a far-reaching time horizon will assist the government in focusing their efforts, policies and legal declarations.

1. INTRODUCTION

Southeast Asia is one of the fastest growing regions in the world in terms of gross domestic product (GDP), population, and demand for both food and energy. There is, therefore, an urgent need to decarbonise the economies of the region, whilst also modernising their energy systems. While the region's rising fossil fuel demand – especially for oil – has outpaced its production (IEA, 2019) there are some encouraging signs for the development of renewable sources.

With economic growth exceeding 4% annually, Southeast Asia's energy consumption has doubled since 1995 and the energy demand is expected to continue growing at 4% per year through 2040 (ACE, 2015b). By 2040, it is estimated that Southeast Asia's oil demand will surpass nine million barrels per day (mbpd), up from just above 6.5 mbpd today (IEA, 2019).

In 2018, some 75% of primary energy demand came from fossil fuel such as oil, coal and gas, and a further 10% from traditional uses of solid biomass (IEA, 2019). Around 250 million people in the ASEAN (Association of Southeast Asian Nations) region still rely on traditional biomass for cooking, particularly in Myanmar, Indonesia and Vietnam (IRENA, 2018).

THE IMPACT OF COVID-19 ON ENERGY DEMAND–SUPPLY DYNAMICS IN ASEAN MEMBER COUNTRIES

The restrictions on mobility and economic activities imposed by various countries across the Southeast Asian region due to the COVID-19 pandemic have impacted energy demand. The constraints on economic activities (closures of restaurants, malls and factories, among others) resulted in a net decrease in energy demand (OECD, 2020a), despite being partially offset by higher energy demand in the residential sector.

In some countries, a shift towards renewables was noted due to depressed electricity demand, low operating costs and priority access to the grid through regulations (IRENA, 2020b).

ASEAN'S RENEWABLE ENERGY ASPIRATIONS

Across the region, policy makers have sought to move towards more secure, affordable and sustainable energy pathways. For ASEAN to achieve its United Nations Sustainable

Development Goals (SDGs), and specifically to localise the SDGs at the subnational and local levels (ASEAN, 2018), and achieve the well-below 2°C temperature goal set out in the Paris Agreement, there is a shared challenge to achieve a major transition away from traditional fossil fuels. Such a transition would require, in many segments of the energy market, increasing use of biomass as the primary energy source. The table below summarises renewable and bioenergy targets for the five countries studied in this report:

TABLE 3: Five studied ASEAN countries' renewable and bioenergy targets

Country	Renewable and bioenergy targets	Source
Indonesia	23% renewable share of TPES (around 92.2 Mtoe in 2025), which consists of 69.2 Mtoe (45.2 gigawatts (GW)) for electricity and 23 Mtoe for non-electricity 31% renewable share in 2050 **Biofuel mandates:** E20 by 2025 and E30 by 2030 B30 by 2020/2025	National Energy Policy (Government Regulation No.79/2014); Ministry of Energy and Mineral Resources Regulation No. 12/2015
Thailand	30% renewable energy in total energy consumption by 2036 4 683 MW by 2037 from biomass and biogas power plants **Biofuel mandates:** Currently E85, E20, E10, terminate gasoline Currently B5 and B10	Power Development Plan 2018 revision 1 15-year Renewable Energy Development Plan (2008–2022)
Vietnam	21% renewable energy in total installed capacity by 2030 and 10.7% of electricity production by 2030 (of which 2.1% will be bioenergy) **Biofuel mandate:** 13% of transport sector's oil consumption (blended 20–30%) in 2040	Vietnam Power Development Plan VII (revised)
Malaysia	20% renewable energy in the power capacity mix by 2025 (excluding large-scale hydro); 9% renewable share of electricity generation by 2020 and 20% by 2030 **Biofuel mandate:** B20	Sustainable Energy Development Authority, Malaysia
Myanmar	12% share for renewable energy in national power generation mix by 2025 (excluding large-scale hydro) **Biofuel mandate:** E10 (plan to mandate)	Ministry of Electricity and Energy

Source: ACE (2015b)

BIOENERGY POTENTIAL IN SOUTHEAST ASIA

There is significant bioenergy potential in Southeast Asia. The key challenge is deploying pragmatic, technically feasible and economically viable solutions that facilitate sustainable bioenergy production.

Countries such as Malaysia, Indonesia and Thailand have already carried out a number of bioenergy projects by utilising agriculture products such as palm oil, sugarcane, corn, cassava and rice to produce energy, and a number of countries have also developed targets or strategies to further promote bioenergy development. Apart from some biodiesel and bioethanol projects, most of the projects are being implemented at small scales and mainly in facilities such as sugar or rice mills to generate power and heat for on-site use.

Significant potential remains untapped for further development. To better understand how this potential may be realised, the objective of this study is to analyse the pragmatic applicability of various types of such biomass feedstocks and develop a biomass strategy for sustainable bioenergy production in the target Southeast Asian countries.

The transition from fossil fuels towards renewable energy to make the energy sector cleaner is clear for countries within the ASEAN. According to the ASEAN Plan of Action on Energy Cooperation Phase II: 2021–2025, ASEAN has set out to make 23% of its primary energy renewable by 2025, compared to 13.9% in 2018, and modern forms of bioenergy are considered as part of the transition (ACE, 2015a).

Figure 1 provides potential energy transformation scenarios in Southeast Asia under both a Planned Energy Scenario (PES) and a Transforming Energy Scenario (TES) (IRENA, 2020a). These scenarios are drawn from IRENA's Global Renewables Outlook; the PES considers policies in place at the time of the report, while the TES outlines a "well-below 2°C" energy pathway consistent with the aims of the Paris Agreement.

Other benefits that may arise from the utilisation of biomass as an energy source in the Southeast Asian region include the following:

- direct impacts on waste management by diverting waste and agricultural residual that would otherwise be disposed of and converting it to bioenergy;
- reduced consumption of fossil fuels, thereby mitigating high greenhouse gas emissions;
- resilient employment[3] opportunities across the whole value chain, from farmers producing biomass feedstock to engineers designing, constructing, operating and maintaining the facilities used to convert the feedstock to bioenergy;
- additional resilient job creation across the entire value chain – unlike other renewable energy sources – as biomass is the only currently viable renewable energy option where direct electrification cannot occur; and
- the provision of additional revenue streams for business owners in the agricultural/ forestry sector, as the waste that is produced from their core businesses can be sold for conversion to biofuel.

3 Resilient employment – or resilient job creation – is defined in this study as the creation of jobs that are sustained for prolonged periods of time in lieu of temporary job creation (i.e. jobs created for 2–4 years during construction of facilities).

FIGURE 1: Energy transformation scenarios in Southeast Asia (TPES)

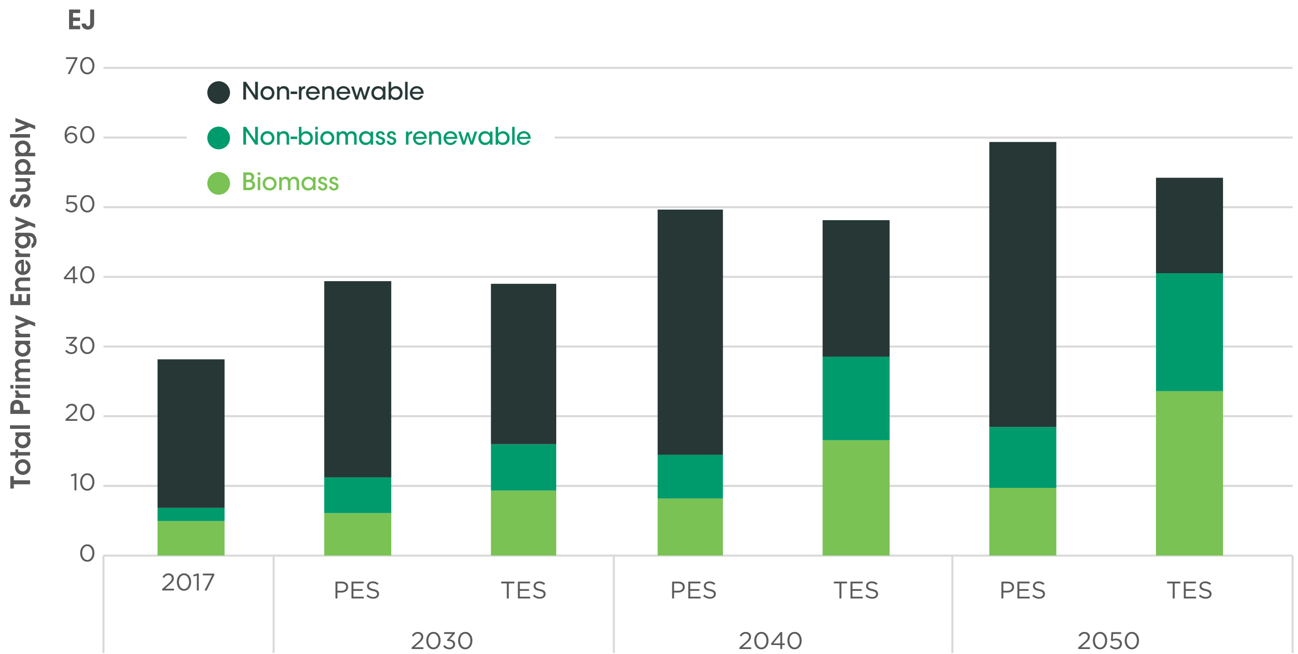
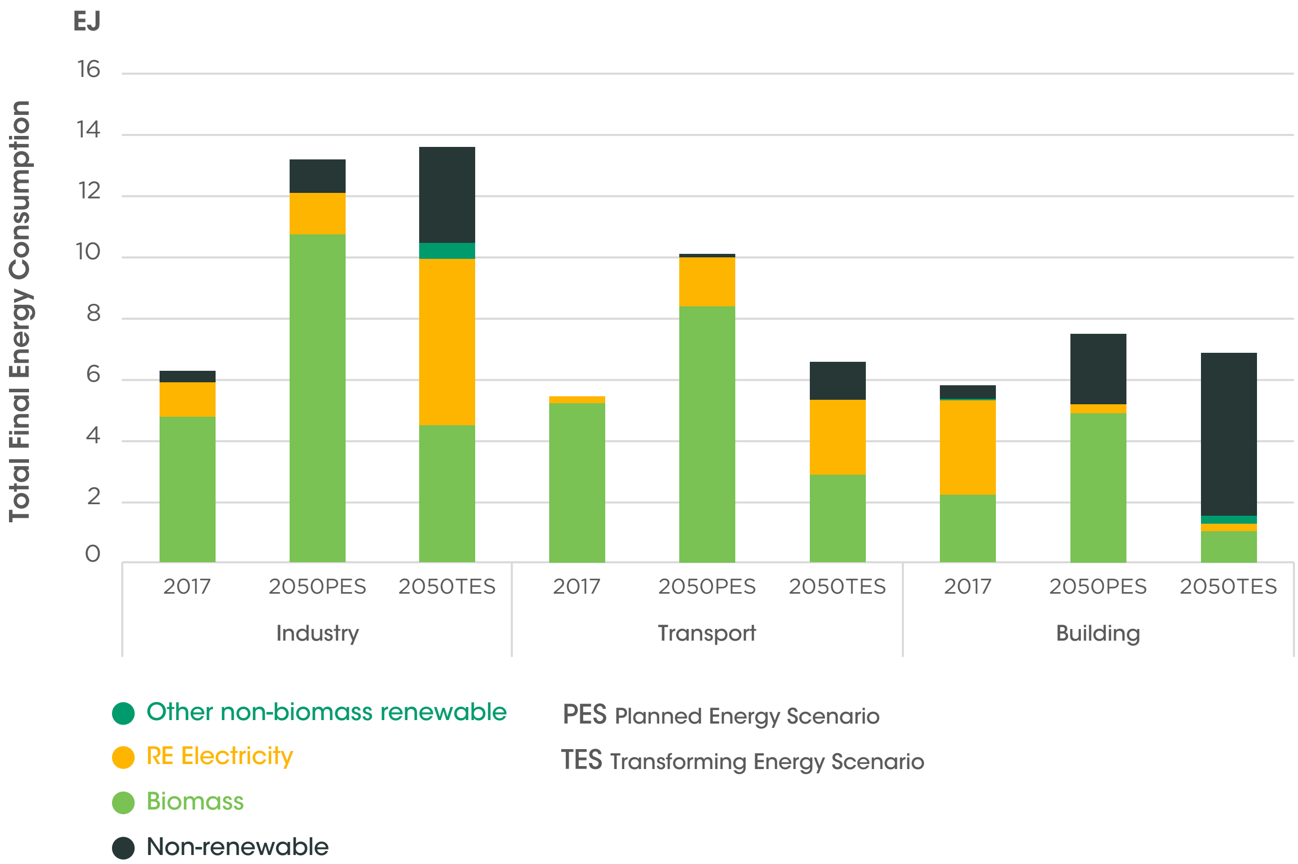


FIGURE 2: Energy Transformation Scenarios in Southeast Asia (TFEC)



Source: IRENA (2020a)

Bioenergy is currently one of the most common renewable energy applications in the region, serving as fuel for industry, buildings, transport and power supply.

TABLE 4: Roles of modern forms of bioenergy in energy sectors

Sector	Role
Power	Providing renewable electricity and flexibility to balance expansion of variable wind and solar power
Industry	Biomass can efficiently supply heat in energy-intensive industrial process
Building	Biomass provides the feedstock for highly efficient district heating systems
Transport	Liquid and gaseous biofuels can help achieve a reduction in fossil fuel use

Bioenergy should be expanded in industry and transport while traditional uses of biomass for building that are associated with forest degradation and indoor air pollution should be phased out. Bioenergy and electrification should play a major role in the future energy mix in Southeast Asia while gradually reducing fossil fuel consumption. Biomass could also play an expanded role in electricity generation, with its installed capacity expected to grow from 7 GW in 2017 to 176 GW in 2050 under the TES.

As shown in the existing literature, huge potential for further deployment of bioenergy exists in Southeast Asia (IEA, 2019; IRENA, 2017a; Junginger, Koppejan and Goh, 2020). This study seeks to examine selected biomass feedstocks in Indonesia, Thailand, Vietnam, Malaysia and Myanmar, and presents the potential socio-economic benefits that could be unlocked through their conversion into bioenergy. Potential key barriers to these bioenergy pathways, and the key interventions required to further deploy bioenergy, are identified through a PESTEL&F (political, economic, social, technical, environmental, legal and financing) analysis.

THE IMPORTANCE OF SUSTAINABLE SOURCING OF BIOMASS

In its simplest form, sustainable bioenergy refers to biofuel produced in a sustainable manner. The Roundtable for Sustainable Biomaterials (RSB) proposed 12 principles for sustainable biofuels in 2008 (revised in 2010) which cover a wide range of social, economic and environmental issues such as air quality, greenhouse gas emissions, water resources, agricultural practices, biodiversity, food security, labour conditions and cost effectiveness (RSB, 2016). The overarching purpose of the principles is to provide a framework for feedstock producers, feedstock processors, and biofuel producers and blenders to mitigate unintended consequences from biofuel production.

The benefits derived through increased biofuel consumption can be improved by implementing sustainable activities throughout the supply chain, from production through to supply and consumption. If appropriate policies are implemented to provide long-term support to facilitate sustainable bioenergy throughout the supply chain, sustainable bioenergy can meet global food needs and climate goals as well as promote economic activities, create jobs, enrich the land and improve livelihoods (Souza et al., 2017).

SUSTAINABLE BIOENERGY'S ROLE WITHIN THE ENERGY MIX

Around 75% of ASEAN's energy demand is currently served by fossil fuels such as coal, of which the total consumption was 331 million tonnes in 2019 (IEA, 2019) the. ASEAN nations rely on fossil fuels – especially coal and natural gas – for providing energy in industrial applications, transport and electricity generation. More specifically, these activities rely on fossil fuels to produce heat, which makes it challenging for these to be substituted with more established forms of renewable energy (namely hydro, solar and wind). Therefore, this report investigates the proportion of fossil fuels that can realistically be substituted with bioenergy to serve regional energy demand. From IRENA's Global Energy Transformation: A roadmap 2050 report, bioenergy would become the largest energy source in the final energy mix in Southeast Asia, accounting for over 40% of TPES in 2050 under the TES. The majority of this would be used in the industry (40% of total bioenergy supply) and transport sectors (37% of total bioenergy supply).

→ **Decision makers require a robust bioenergy transformation plan to reduce dependency on fossil fuels and strengthen national resilience and energy security. The key barriers and interventions identified in this study can guide policy makers in developing transformation plans.**

This report comprises five sections:

- **Section 1** (this section) introduces the study, providing both background and context.
- **Section 2** introduces the approach employed to identify potential bioenergy pathways and provides a detailed explanation of the methodology used. It also analyses the potential socio-economic benefits from these bioenergy pathways and suggests the key interventions required to unlock these benefits.
- **Section 3** details the findings and analysis for each target country and presents key barriers and associated interventions to implement a transition to biomass as the primary energy source (in cases where the pathway identified is projected to provide the desired socio-economic benefits).
- **Section 4** presents lessons learnt from case studies that can provide practical teachings for stakeholders seeking to implement the recommendations of this study.
- **Section 5** summarises the findings of the study and proposes specific actions for a wide range of stakeholders to prepare for the implementation of attractive bioenergy pathways.

2. METHODOLOGY

This study maps out and analyses the entire biomass value chain through a three-step process, as set out below. A market economics-based approach is utilised to logically develop the bioenergy pathways.

FIGURE 3: Methodology – the three-step approach

1 Bioenergy Pathway

- Identify bioenergy pathways and estimate market contestability for short (2025), medium (2030) and long-term (2050) horizons
- Focus placed on analysis of appropriate sectors for each country (i.e. industry and transport sectors for Indonesia and use of woody biomass for Myanmar)

2 Bioenergy Economics

- Analyse the economic costs and benefits of each bioenergy pathway
- Produce a Benefit-Cost Ratio (BCR)
- Estimate the total economic net present value (ENPV) of total economic costs and benefits

3 Identifying Key Benefits and Interventions

- Develop a bioenergy transformational roadmap
- Identify key challenges and required interventions
- Analyse the political, economic, social, technical, environmental, legal and financing (PESTEL&F) dimensions of an enabling framework

Step 1: Mapping bioenergy pathways

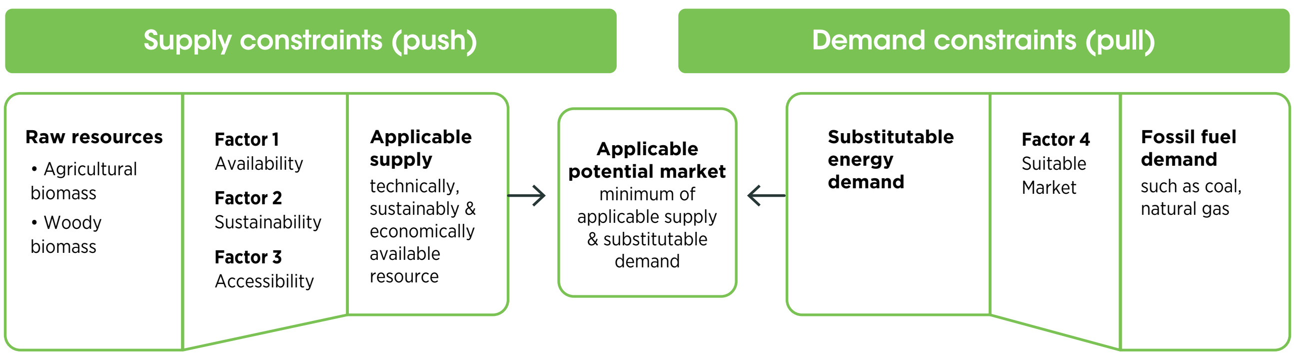
In step 1, bioenergy pathways were designed around four key market "push and pull" factors to facilitate demand-driven market transformations:

- Factor 1: availability;
- Factor 2: sustainability;
- Factor 3: accessibility; and
- Factor 4: substitutable market.

This step provides respective governments with an outline of: the conversion routes from identified biomass feedstocks to bioenergy; the potential bioenergy available for end-use applications for the short- (2025), medium- (2030) and long-term (2050) horizons; and the appropriate market where bioenergy could be utilised as an alternative renewable energy source.

Both supply (push) and demand (pull) constraints were taken into consideration. Emphasis was placed on identifying appropriate supply and demand constraints to provide a holistic understanding of the factors. Lastly, conversion efficiency adjustments were made to the applicable supply to make it comparable to fossil fuel demand. The applicable potential market that is the minimum of the two represents a realistic market for each pathway identified. This approach is illustrated below:

FIGURE 4: Push and pull factors



FACTOR 1: AVAILABILITY

The high productivity of Southeast Asia's agriculture sector generates considerable volumes of residuals that remain under-utilised. Three of the ASEAN member countries – Indonesia, Thailand and Vietnam – were chosen as target countries for the broader analysis in this study due to their large agricultural industries and subsequent potential for untapped biomass feedstock. Meanwhile, Malaysia and Myanmar were selected to conduct the analysis on woody biomass.

Private financiers of renewable energy projects often cite security of bioenergy supply as one of the biggest obstacles to investment. A broad range of issues determine the total available volumes of bioenergy that can provide security of supply to energy markets, such as biomass scalability and seasonality. As biomass feedstocks have faced major challenges in scalability (Richard, 2010), this study only selected a maximum of three agricultural crops for the use of harvest and process residues for bioenergy feedstocks in each country to ensure the most scalable bioenergy feedstocks are prioritised. Woody biomass that can be sourced from plantation forests is also analysed.[4]

The seasonality of biomass outputs can also impact the continuity of biomass feedstock availability, as a reduction in crop production will decrease the residuals that can be used as biomass feedstock. Governments can mitigate this is by forming a central collection agency to plan the collection of agricultural residuals from various agricultural practices and crops throughout the year and distribute them systematically according to demand.

→ **There is an abundance of untapped bioenergy in the ASEAN region; however, decision makers need to create frameworks that offer robust bioenergy pathways and give confidence to private financiers in the security of bioenergy supply to service energy markets.**

FACTOR 2: SUSTAINABILITY

Sustainable bioenergy has been successfully pioneered in Europe, Japan and the United States, where these issues have been addressed through:

- diligent stewardship to ensure that bioenergy is sustainably sourced;
- initially sourcing biomass from agri-industry process residuals, thereafter expanding to include sourcing from agricultural residuals;
- aggregating biomass feedstocks to mitigate quality and volume risks from factors such as seasonal variations, changes in agricultural crops etc.; and
- use of fuel enrichment technologies to provide consistent quality of bioenergy fuel with a calorific value that positions it as a viable alternative to fossil fuels.

4 It should be noted that other agricultural crops (e.g. coconut and maize in Indonesia) that are not covered in this analysis also have considerable potential for use as feedstocks.

BOX 2: CASE EXAMPLE – DRAX BIOMASS POWER STATION

- The Drax Power Station is one of the UK's largest power stations, with a total capacity of nearly 4 000 MW. Situated near Selby in North Yorkshire, Drax comprises three biomass-fired units that have been converted from coal combustion, and three coal-fired units, which are now scheduled to also be converted to biomass.
- Around 70% of its current generation is now fuelled by compressed wood pellets rather than coal and the plant will ultimately be converted to 100% bioenergy.

Drax's efforts to source biomass sustainably

- The plant currently burns about seven million tonnes of biomass annually.
- Sustainably-sourced biomass includes:
  - responsibly-sourced sawmill residues that do not cause deforestation, degradation or displacement of solid wood products;
  - forest residues from regions with high rates of decay, or where this material is extracted to roadsides as part of standard harvesting practices;
  - thinnings that improve the growth, quality or biodiversity value of forests; and
  - roundwood that helps to maintain or improve the growing stock, growth rate and productivity of forests.

As this study is concerned with biomass feedstocks that can be produced in socio-economically and environmentally-sustainable ways, the identification and analysis of bioenergy pathways is based on the untapped biomass feedstock that no land-use change associated with bioenergy feedstock production is anticipated, and that the demand for food and feed is not distorted by bioenergy feedstock production, despite population increases.

Environmental and social (E&S) factors need to be taken into consideration when evaluating biomass feedstock feasibility and costs for respective bioenergy pathways, as detrimental E&S impacts can significantly impede implementation and raise reputational risks.

→ **Strengthening sustainability stewardship practices through institutional and industrial capacity-building will increase resilience, availability and security of supply, whilst also increasing the attractiveness of the sector to private financiers – especially those investing using ESG criteria.[5]**

5 ESG investment criteria include: 1) environmental (resource use, emission, innovation); 2) social (workforce, human rights, community, product responsibility); and 3) governance (management, shareholders and CSR strategy) factors.

FACTOR 3: ACCESSIBILITY

Volumes of accessible bioenergy resources will increase over time through increased market awareness, improved logistics chains, technology enhancements and increased private financing appetite.

The accessibility of biomass feedstock will directly impact how scalable the respective bioenergy pathway is, which in turn impacts the number of socio-economic benefits that can be derived from its implementation. Some accessibility factors that this study considers include the location of potential biomass feedstock, and the adjacent transport and logistic infrastructure that would facilitate its collection and transportation.

While both process and harvest residues were considered in this study, process residue should be prioritised over harvest reside, as it is easier to access, collect and transport due to the current infrastructure in place. However, the deployment of biomass for more challenging sectors such as the cement industry will require additional logistical arrangements, as the current use of biomass for the industry sector is limited to food and wood processing industries with easy access to feedstock.

→ **Identifying accessible biomass feedstock in the short term, and constructing infrastructure that increases biomass accessibility in the medium and long terms, will directly impact the scalability of feedstock and positively improve potential socio-economic benefits.**

FACTOR 4: SUBSTITUTABLE MARKET

'Substitutable' market in this study encapsulates the identification of current markets and their uses of fuels – such as consumption of brown coal for industrial heat generation. This aspect of the study analyses whether the bioenergy pathways selected can reasonably be applied to position biomass as a substitute energy source. Additionally, the potential market is selected based on the commercial viability, technical constraints and comparative advantages of replacing fossil fuels with biomass. Only when substitutable markets are identified are bioenergy pathways (see Table 5) considered viable in this study. The core reasoning behind this is that even if there is plenty of biomass feedstock available, a bioenergy pathway cannot reasonably penetrate a given market without being recognised as an appropriate substitute for conventional fuels.

For example, when biomass feedstock is considered as a substitute fuel source for the industrial direct heat generation process, low-grade brown coal is considered replaceable, as solid biomass has a similar heating value to brown coal. The use of biomass as a substitute for coking coal is considered more challenging, while small-scale applications of charcoal and bio-coke for furnaces at steel making plants have been demonstrated. Higher replaceability is considered in the medium and long term, when the technical constraints are eased via research and development.

In order to improve the commercial viability of biofuel as a substitute fuel source, co-ordinated economic planning of energy markets must consider different planning horizons, as well as the utilisation and replaceability of sustainable bioenergy.

→ **Governments must look carefully at the pull factor to identify appropriate substitutable markets. Demand for biofuel as a substitute may improve with technological innovation and the increasing need for decarbonisation.**

TABLE 5: Main technologies for bioenergy pathways

Technology	Description
Direct combustion of biomass for industrial heat generation	Direct combustion for industrial heat generation refers to burning solid biomass for the generation of heat in industrial processes as a substitute for brown coal. Direct combustion for brown coal is the norm across the cement and paper industry today, whilst utilising rice husk for co-firing in the cement industry has also been explored as an alternative energy source (Zareei et al., 2017). The feedstocks used for this pathway comprise pre-treated biomass derived from agricultural residues and wood in the form of pellets or torrefied pellets. The coking coal used in the blast furnaces of iron and steel industries can be partially replaced by biomass substitutes like charcoal (bio-coke) via co-firing. The blending ratio is determined with due consideration of the operational sizes of blast furnaces. Prior studies have deduced that by 2030, about 10% of charcoal can be co-fired at most commercial blast furnaces with conventional coking coal. This ratio can gradually be improved to 25% by 2050. A further increase in blending ratio might severely affect the efficiency of furnaces and the quality of iron due to the relatively low mechanical strength of biomass substitutes (Fick et al., 2014)
Direct combustion of biomass for combined heat and power generation	This technology uses the same biomass feedstock as for industrial heat generation but for heat and power generation in CHP plants. The purpose of doing so is to present an alternative substitutable market for the same biomass feedstock. This conversion process involves collection, pre-treatment, and combustion of biomass to generate both heat and electricity. The high conversion efficiency of CHP presents a commercially attractive case for the use of biomass feedstock. By employing torrefaction, biomass can also be directly used or co-fired with coal in the plant. Torrefaction is a pyrolysis process which utilises a low heating rate with a temperature below 300°C in an inert condition which converts biomass feedstock into a low emission solid fuel with high energy content (Alamsyah, Siregar and Hasanah, 2017). Some coal-fired power plants in Europe (e.g. Lynemouth Power Station in Northumberland, UK) have successfully converted themselves into biomass-fired power plants using pellets as feedstock.
Anaerobic digestion to generate biogas for both heat boilers and CHP plants	Anaerobic digestion refers to a process through which bacteria breaks down organic matter without oxygen to produce biogas which will be used in both heat boilers and CHP power plants. This study focuses on the potential to utilise this conversion process to produce a substitute energy source for natural gas used in in heat boilers in the short term, and in CHP plants in the medium and long terms.
Fermentation & blending to produce bioethanol	Fermentation and blending refer to the use of sugarcane molasses to produce ethanol via a fermentation process, and blending with gasoline for transportation and industry uses. This study focuses on the potential to utilise this conversion process to create a substitute for conventional gasoline.

Step 2: Quantifying bioenergy economics

Bioenergy economics is used to appraise the demand for bioenergy versus the potential available supply, using economic value. Associated economic costs are estimated and compared with estimated socio-economic benefits through a high-level socio-economic cost–benefit analysis based on the following two key economic parameters:

ECONOMIC NET PRESENT VALUE (ENPV)

Evaluates the difference between the present value of socio-economic benefits and present value of economic costs over a period, discounting future amounts to current values at a specified social discount rate. ENPVs for different proposed bioenergy pathways provide the rationale for accelerating fuel switching from fossil fuels to bioenergy that can bring positive socio-economic benefits.

BENEFIT–COST RATIO (BCR)

Compares the relative economic costs and socio-economic benefits of a proposed bioenergy pathway. If the proposed bioenergy pathway has a BCR greater than 1.0, it is expected to deliver a positive net present value to the country. Comparing BCR ratios for different proposed bioenergy pathways provides a basis for prioritising those bioenergy pathways that can most quickly achieve economic efficiencies.

The bioenergy economics analysis considers the economic costs and benefits as outlined in the table below.

TABLE 6: Economic costs

Total economic costs	Brief methodology
Capital expenditure (CAPEX)	A unit CAPEX of biomass infrastructure for each pathway is used that covers the full investment cost
Operational expenditure (OPEX)	A unit OPEX cost is used that includes the biomass feedstock cost, logistic cost, processing cost, and other operation and maintenance (O&M) costs.

TABLE 7: Socio-economic benefits

Total socio-economic benefits	Brief methodology
Total economic benefits of improving energy security	Avoided GDP loss during supply disruption: current and future percentage of fuel price change, fuel-GDP elasticity and GDP per country, and percentage replacement of imported fuel with biofuel[6]
Total avoided cost from construction of plants for conventional fuel	Typical development cost of the replaced plant/refinery (gasoline/coal/natural gas), retrofitting or development cost of new build
Total avoided environmental costs	Net avoided greenhouse gas emissions cost from traditional gasoline/coal vs. biomass
Total contribution to economy from resilient employment	Net contribution to the economy through wages created from the bioenergy value chain, offset against the current domestic employment in the substituted energy segment for farming and non-farming jobs

6 Note that this only applies to pathways where the country is a net importer of the fuel replaced.

Step 3: Identifying key barriers and interventions

Each target country's current bioenergy climate is analysed using political, economic, social, technical, environmental, legal and financing (PESTEL&F) dimensions to identify key barriers limiting bioenergy potential. Specific interventions for each barrier identified are then presented to help target countries to mitigate existing barriers and unlock the socio-economic benefits identified in Step 2.

The elements considered for each PESTEL&F dimension are further described below.

TABLE 8: Elements considered in each PESTEL&F dimension

Dimension	Elements considered
Political	Effectiveness of the national government in supporting bioenergy deployment
	Availability of fiscal or market support for bioenergy transition
Economic	Benefit–cost ratio
	Unit cost (cost/PJ)
Social	Whether the selected biomass pathways will have any negative or synergetic impacts on other industries, such as food
	Resilient employment through production of biofuels (benefit from resilient employment in million USD/PJ)[7]
Technological	Extent of changes required to current collection, logistics and processing infrastructure to make bioenergy available
	Extent to which technology is already commercially proven in the market
Environmental	Beneficial reuse of biogenic carbon resources that would otherwise be fed into waste streams
	Impact on greenhouse gas emissions (measured as GHG emission reduction benefit in million USD/ tonnes CO_2 equivalent)
	Negative competitive impacts on land-use
Legal	Existence of a regulatory framework that supports increased bioenergy production to reduce reliance on fossil fuels (Jull et al., 2007) and availability of a sustainable supply of bioenergy backed by the legal enforcement capacities of government authorities
Financial	Security of revenue as a basis for raising leveraged finance and establishing an enabling environment for investment in bioenergy scale-up

7 Benefits are calculated as net job benefits, meaning the figure accounts for lost jobs in identified markets where bioenergy can act as a substitute energy source. Contribution to the economy is estimated by multiplying net jobs with average wages in applicable sectors.

3. COUNTRY-SPECIFIC FINDINGS

Indonesia, Thailand, Vietnam, Myanmar and Malaysia were identified as the five target ASEAN countries for this study. Indonesia, Thailand, Vietnam and Malaysia were selected based on IRENA's Southeast Asia Renewable Market Analysis (IRENA, 2018), whilst Myanmar was selected due to its current high rate of deforestation (Myanmar Times, 2015), which poses challenges for the transition from traditional to modern bioenergy. In all cases, target countries were chosen based on the extent to which the findings of this study could provide valuable information to aid them in their transition to biomass as their energy source.

The findings, including socio-economic benefits, key barriers and key interventions for each target country, are presented below.

a. Indonesia

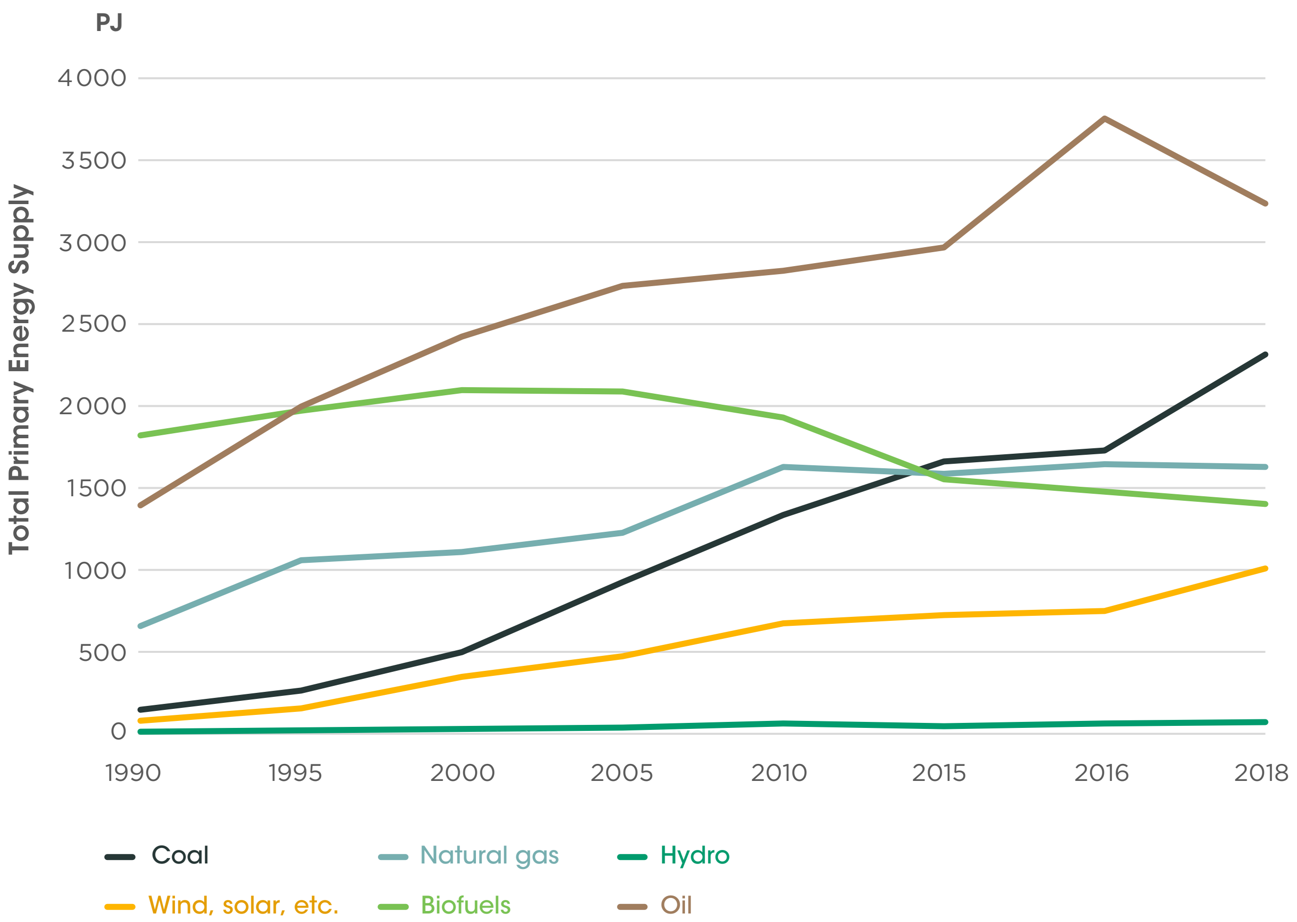
There is significant potential for socio-economic benefits to be unlocked by utilising biomass feedstock produced in Indonesia from its large agricultural and forestry industry.

Indonesia is the largest archipelago in the world, with approximately 55 million hectares of agricultural land and approximately 98 million hectares of forest (FAO, 2020a). Indonesia's large land mass, coupled with its abundant rain and sunshine throughout the year, facilitates a thriving agricultural sector. This translates into significant potential for biomass feedstock supply, accessibility and sustainability.

As presented in Figure 5, bioenergy is the largest energy source among renewables in Indonesia, with primary supply amounting to around 1 400 PJ in 2018. A majority of the country's renewable energy use comprises traditional uses of bioenergy (mainly for cooking in the residential sector) in the country's rural areas and remote islands

(IRENA, 2017b), which is a major driving force for forest degradation leading to substantial GHG emissions.[8] The supply of bioenergy has decreased since its peak of 2 140 PJ in 2008, as access to electricity has improved in rural areas.

FIGURE 5: Total primary energy supply in Indonesia, 1990–2018



Source: IEA (2020)

While its demand for energy continues to grow, Indonesia risks relying more on fossil fuels such as coal, natural gas and oil in its energy mix. To set a course for climate compatible pathways, it is of critical importance to reverse this trend and embark on an energy transition in which bioenergy plays an essential role.

Potential bioenergy pathways identified through the four push and pull factors outlined in Section 2, and that include the identification of potential biomass feedstock, the type of biofuel conversion process, and the potential for final application, are presented below.

8 Note that although the share of traditional bioenergy use in the energy supply mix has declined, an estimated 24.5 million households (40% of Indonesian households) still rely primarily on fuelwood for cooking. This practice results in indoor air pollution which is associated with 165 000 premature deaths in Indonesia each year (IRENA, 2017b).

Bioenergy pathways

Identifying available biomass feedstocks in Indonesia

I. PALM OIL MILL EFFLUENT

As the world's leading producer and exporter of palm oil (Green Palm Sustainability, 2015), palm oil is expected to constitute a major part of the agricultural economy in Indonesia. The sustainability of biodiesel derived from palm oil remains a matter of debate; yet while Palm oil plantations have been developed primarily for the purpose of meeting the growing demand for edible oil, palm oil can be also used in many different applications such as personal care, cosmetics and pharmaceuticals, as well as industrial oils such as lubricants and surfactants.

This study explores the use of Palm oil mill effluent (POME) generated along the value chain in the energy system as a potential biomass feedstock.

BOX 3: DEFORESTATION AND AGRICULTURAL COMMODITIES

Historically, emissions from land use change – principally those associated with deforestation and expansion of agricultural production for food – are estimated to have contributed roughly one-third of accumulated anthropogenic carbon emissions (Berndes et al., 2013). Conversion from forests to agricultural land was most prevalent in the temperate climatic domain until the late 19th century; since then, the tropical rainforests have become the focus of deforestation.

In the last three decades, an estimated 420 million hectares (ha) of forest has been lost to deforestation, of which more than 90% was in the tropical domain. Indonesia ranked second in terms of the net loss of forest cover, losing 26 million ha during the same period, after Brazil, which lost 92 million ha (FAO, 2020e).

Large-scale commercial agriculture (primarily cattle ranching and cultivation of soybean and oil palm) and local subsistence agriculture are the two most prevalent drivers of deforestation, accounting for 40% and 33%, respectively (FAO, 2020f). In Indonesia, oil-palm plantations have expanded by around 14.7 million ha, accounting for 23% of the country's forest loss between 2000 and 2016 (2020 NYDF Goal 2 Progress Assessment). Although the establishment of oil palm plantations is primarily driven by the global edible oil market, the production of biofuels has, to some extent, contributed to the conversion of forests (OECD and FAO, 2016).

While the REDD+ (reducing emissions from deforestation and forest degradation) program is being carried out under UNFCCC with the aim to provide financial incentives for developing countries to reduce deforestation, another notable milestone to address deforestation is the New York Declaration on Forests (NYDF) which was launched at the UN Climate Summit in 2014 and endorsed by more than 200 governments and organisations. It sets out ten goals with the aim to ultimately halt deforestation by 2030. Goal 2 is to support and help meet the private sector goal of eliminating deforestation from the production of agricultural commodities such as palm oil, soy, paper, and beef products by no later than 2020.

According to the 2020 Goal 2 progress assessment report, of those companies exposed to forest risk assessed by the Forest Trends' Supply Change initiative and Global Canopy's Forest 500 project, more than half had made public commitments to address deforestation. It also found that companies in the palm oil, and pulp and paper sectors in Southeast Asia "are consistently more advanced than their counterparts in cattle and soy supply chains in Latin America". The report also concludes that, in 2018, 81% of Indonesian palm oil exports were derived from a small number of companies that had adopted "no deforestation, no peat and no exploitation (NDPE)" practices.

However, several challenges remain in order to effect real change toward halting deforestation. These include, amongst others, making companies' commitments workable by strengthening vertical integration with their subsidiaries and suppliers as well as promoting landscape or jurisdictional approaches whereby biofuel market stakeholders are also horizontally integrated in the sustainability governance framework.

POME is a high-concentration wastewater discharged from palm oil mills. It has a BOD value of 30 000–50 000 mg/litre and a COD value of 30 000 mg/litre, which is 500–800 times higher than that of public sewage in Thailand (Lokman et al., 2021; WEPA, 2020). The most common method to treat POME is the open ponding system. This system being considered the most economical option for POME treatment. However, it remains land- and time-intensive, and produces methane in large quantities from POME decomposition.

Channelling POME into land applications or water bodies has proved detrimental to vegetation or aquatic environments if it does not meet environmental standards set by the government (Walker et al., 2018). To mitigate water pollution, a growing number of mill operators are adopting covered lagoon systems to capture methane and convert it to carbon dioxide by flaring. However, putting up covers on lagoons alone does not lower the BOD value of POME to environmentally acceptable levels, so mill operators are required to take further additional measures such as membrane treatment and active carbon treatment.[9] Current practice for POME treatment is utilising lagoon systems, which consist of several series of lagoons (anaerobic, aerobic, sedimentation) that are 1 ha wide or more and 3–5 m deep to decrease the organic pollutant concentration. Due to the financial burden, many mill operators have not yet adopted this approach.

9 Dischargeable limits for POME into waterways in Indonesia are regulated by KEP 51-/MENLH/10/1995. Because it is difficult to meet the threshold, additional measures need to be taken or a longer HRT required; therefore, most palm oil mills in Indonesia discharge it for land applications, as the permit threshold is not particularly strict (BOD: 5 000mg/L and pH 6–9).

FIGURE 6: Covered lagoon digester

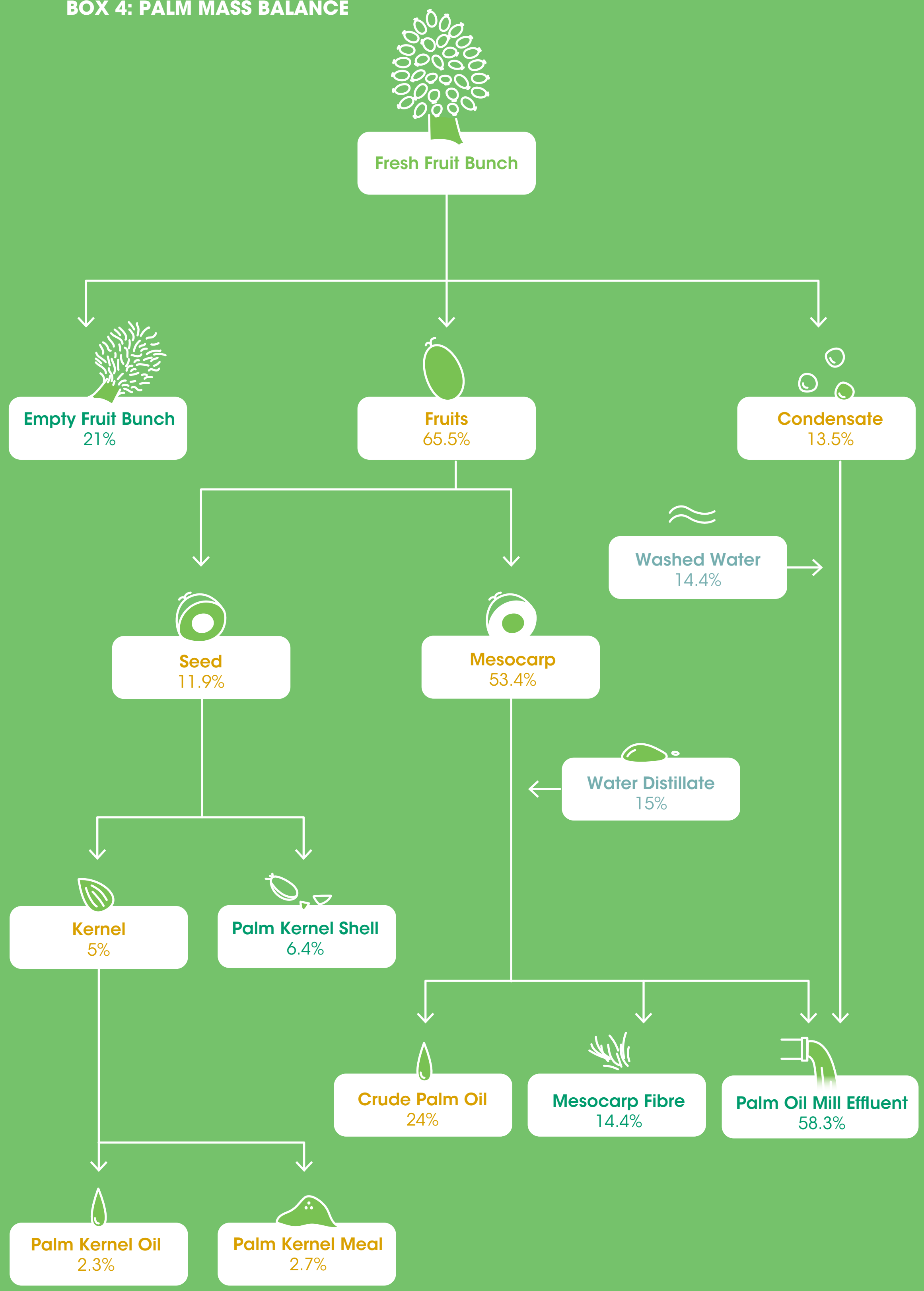
Source: Aqualimpia (2020)

Biogas plants with covered lagoon systems are predominantly used in Indonesia due to their lower investment costs compared to other types of digester processes. Some factors triggering the development of biogas in Indonesia include the Clean Development Mechanism and feed-in tariffs for electricity. However, the following points were noted:

- carbon price has plummeted;
- due to changes to national electricity price regulations, selling electricity is no longer financially attractive; and
- palm oil mills are mostly located in remote areas, far enough from the nearest electricity grid to make financing difficult.

Most of palm oil mills already have sufficient energy supply to run their facilities by utilising on-site residues such as mesocarp fibre and palm kernel shell as fuels for boilers. Also, palm oil mills are typically fitted with their own turbines and generators to fulfil energy demand. Most POME biogas facilities in Indonesia were built for meeting internal energy demand, including for boiler burners. An additional benefit of increasing investment in biogas plants is that more palm kernel shells are available for export or the domestic market (this will increase the benefits for mill owners when palm kernel shell prices are high). Given the huge energy potential of POME, it is important to tap this resource instead of just treating it as waste. This will, in turn, enhance the sustainability of the oil palm sector.

BOX 4: PALM MASS BALANCE



Source: Eriza (2010)

II. AGRICULTURAL RESIDUE, ACACIA AND RUBBER

Indonesia has a thriving agricultural sector that contributed approximately 13% of its total GDP (OECD, 2020b) from 26.3 million ha of arable land in 2018 (FAOSTAT, 2021). The country is a major global producer of palm oil and coconut, mangoes, natural rubber, rice, bananas, coffee, pepper, maize, cassava, pineapple, sweet potatoes, oranges and sugarcane (FAOSTAT, 2021). Among these, the three agricultural crops with the greatest potential for scaling residue-derived bioenergy are oil palm, rice and sugarcane. These include palm kernel shells, empty fruit bunch, old trunks, rick husks, rice straw, sugarcane bagasse, sugarcane tops and sugarcane leaves.

This study aims to identify the top three agricultural crops with the greatest potential for scalability based on the following factors:

- crop production volumes;
- residue-to-crop ratios; and
- current feedstock collection issue.

This will help policy makers and business operators to concentrate their human and financial resources on the pathways with the highest likelihood of successful deployment at commercial scale. In Indonesia, solid residues derived from palm oil, rice and sugarcane production have the greatest potential; these include palm kernel shell, empty fruit bunch, old palm trunk, rice straw, rice husks, sugarcane bagasse, tops and leaves. As an example of biomass feedstock not being utilised to its full potential in Indonesia, it is common practice for old palm trunks and fonds to be left on the ground of plantations to rot as mulch to maintain soil moisture and suppress weed growth. This is a popular practice as it is the cheapest and least labour-intensive way to treat abundant plantation waste.

Indonesia produced over 80 million m^3 of industrial roundwood for sawn timber, plywood, pulp and other fibre materials, and another 40 million m^3 of wood fuel – mainly for traditional cooking – in 2019 (FAOSTAT, 2021). Through the wood value chain, large volumes of residues and waste are generated in various forms such as treetops, branches, low-grade trees, bark, sawdust and residual roundwood following processing into sawn lumber. These residues can be used as feedstock for bioenergy; however, this study focuses on woody biomass that can be sourced from plantation forests, as more in-depth analysis would be needed to assess whether wood extracted from natural forests can be considered as sustainable feedstock.

The major plantations in Indonesia are natural rubber and acacia, spanning 3.64 million ha (Indonesia Investments, 2018) and 1.6 million ha (Hardie et al., 2018), respectively. Indonesia is the 2nd largest producer of natural rubber in the world (FAOSTAT, 2021). It takes seven years for a rubber tree to reach a productive age. Thereafter, it can produce for up to 25 years, at which point natural rubber trees are cut down and replanted. Cut rubber wood can be processed into various types of valuable wood materials, but processing residues can also be used as bioenergy feedstock. Lim, Gan and Tan (2004) have determined that the energy content of rubber wood can be as high as 40 GJ per hectare per year. Acacia is also widely planted to produce wood chips for the pulp and paper industry. It is one of the fastest growing tree species, which is cut down every seven years and replanted on a rotational basis.

III. CASSAVA PULP

Indonesia is the world's fourth largest producer of tapioca, which is a starch extracted from the cassava root. The production of tapioca starch in Indonesia is reported to be approximately 2 million tonnes per year (Triwiyono, 2015), with a total plantation area of around 1.2 million ha.

Cassava pulp is a solid waste by-product of the starch production process. It has a high starch content (50–60% dry basis), causing an environmental problem with disposal (Sriroth et al., 2000). Cassava pulp contains large amounts of carbohydrate, which is favourable for biogas production.

TABLE 9: Indonesia's potential biomass energy sources - selected, available bioenergy feedstock

Type of feedstock	Quantity available (million tonnes)		
	2025	2030	2050
Palm oil residues (PKS, EFB, old trunk)	131.4	138.8	147.3
Rice husks, rice straw	41.6	41.6	41.6
Sugarcane bagasse, tops and leaves	7.5	8.0	8.5
Rubber	12.3	12.9	13.7
Acacia	4.5	4.7	5.0
Palm oil mill effluent (POME)	70.3	74.3	78.8
Cassava pulp	8.9	9.4	10.0
Total	**334.6**	**353.4**	**375.2**

Source: IRENA (2017a)[10]

10 The quantity available for woody biomass provided in the IRENA report, *Biofuel Potential in Southeast Asia*, is estimated based on annual woody biomass increment multiplied by energy wood share. The energy share of total woody biomass is 20% for pulp wood and 40% for lumber and furniture wood. The quantity available for harvest residues is limited to 25% of total harvest residues to ensure soil quality and biodiversity.

This study assumes that the year-on-year increase in quantity of these available feedstocks will be achieved at a rate of 1.1% from 2025 to 2030, and 0.3% from 2030 to 2050,[11] given an assumed increase in production. Throughout this period, no land use change would occur (with a view to halting deforestation), owing to increasing yield per unit of land, and residue-to-crop production ratios remain constant. Yield increases can be made possible by adopting new farming technologies such as mechanisation, cultivar improvement, precision agriculture as well as digital monitoring and weather forecasting.

It is worth noting that demand from conventional use of the residues (for animal feed and bedding, the acacia for pulp and paper, and rubber for timber and furniture) is deducted from the total quantity available.

Identifying collectible biomass feedstocks in Indonesia

The fact that bioenergy feedstocks are available at the site of production does not automatically mean they can be used, because the collection of feedstocks poses several logistical challenges. Many of the agricultural residues are scattered across arable land that is not centrally located for ease of collection. A major challenge in biomass feedstock collection is managing the systematic gathering, collection and transportation of the feedstock. The scale of difficulty in organising and managing the collection of biomass feedstock is a barrier that results in some residues being left uncollected and untreated.

As biomass feedstock becomes gradually available over time, the quantity collected also increases. This study assumes the collection ratio for applicable feedstock[12] will increase from 10% in 2025 to 30% in 2030 and further to 75% in 2050 for agricultural residue, and 30%, 50%, and 90% in 2025, 2030 and 2050, respectively, for woody biomass[13] (refer to the table below).

11 Rice production is declining in Indonesia. In this study, it is assumed to remain at the current production level without further increase.

12 The applicable feedstock excludes conventional use of the residues for animal feed and bedding; the acacia for pulp and paper; and rubber for timber and furniture.

13 Due to lack of available data on how many tonnes of each biomass feedstock type is already used as an energy source, this study assumes that all biomass feedstock analysed in this report are not utilised today and that the collection ratio of agricultural residues and woody biomass will increase over time.

TABLE 10: Indonesia's potential biomass energy sources – selected, collectible bioenergy feedstock

Type of feedstock	Quantity collectible for bioenergy (million tonnes)		
	2025	2030	2050
Palm oil residues (PKS, EFB, old trunk)	13.1	41.6	110.5
Rice husks, rice straw	4.2	12.5	31.2
Sugarcane bagasse, tops and leaves	0.8	2.4	6.3
Rubber	3.7	6.5	12.4
Acacia	1.3	2.4	4.5
Palm oil mill effluent (POME)	7.0	22.3	59.1
Cassava pulp	0.9	2.8	7.5
Total	**31.1**	**90.5**	**231.5**

The increasing quantity of biomass feedstock available over each of the horizons studied directly correlates to an increasing amount of biomass feedstock collectible. Other factors that contribute to this increase include:

- improvements in logistics management;
- improvements in stock-pile management; and
- improvements in surrounding infrastructure.

The biomass feedstock collectible is then converted to petajoules (PJ) in the table below and presented as the estimated potential available primary bioenergy supply in Indonesia for each identified biomass feedstock.

TABLE 11: Indonesia's potential primary bioenergy supply – selected, collectible bioenergy feedstock

Type of feedstock	Primary bioenergy supply (PJ)		
	2025	2030	2050
Palm oil residues (PKS, EFB, old trunk)	197.1	624.5	1 657.6
Rice husks, rice straw	62.4	187.2	467.9

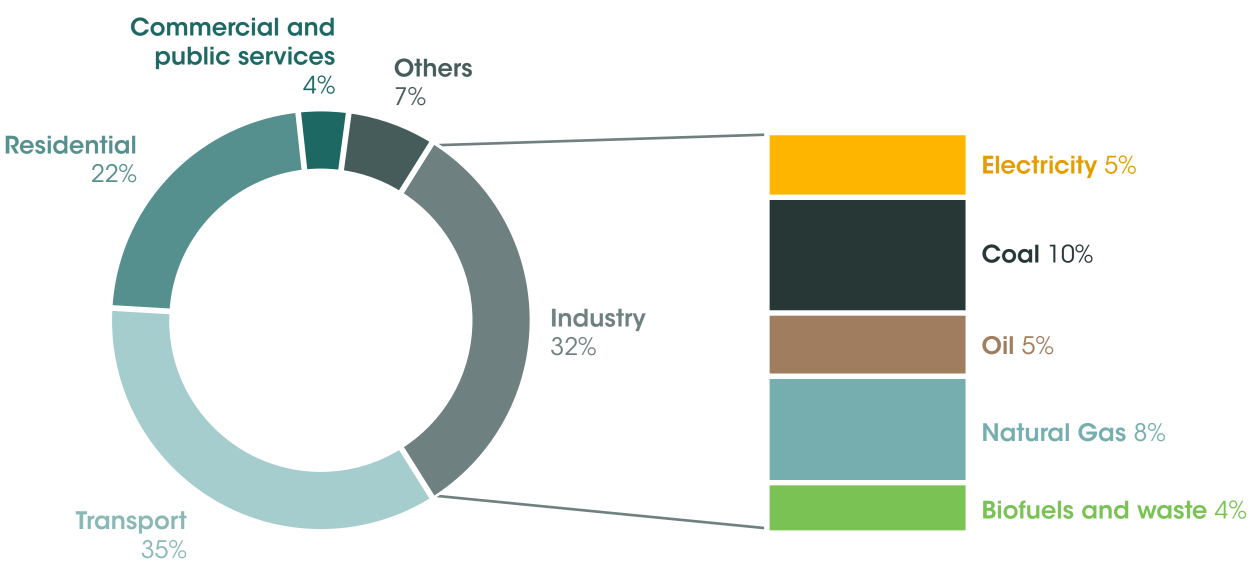
Sugarcane bagasse, tops and leaves	11.3	35.8	95.1
Rubber	69.9	123.0	235.0
Acacia	25.5	44.9	85.9
Palm oil mill effluent (POME)	4.9	15.4	40.8
Cassava pulp	1.2	3.9	12.3
Total	**363.3**	**1 034.7**	**2 594.6**

Indonesia's energy mix

As the final step in mapping bioenergy pathways, the most substitutable end-use markets for bioenergy penetration in Indonesia are analysed.

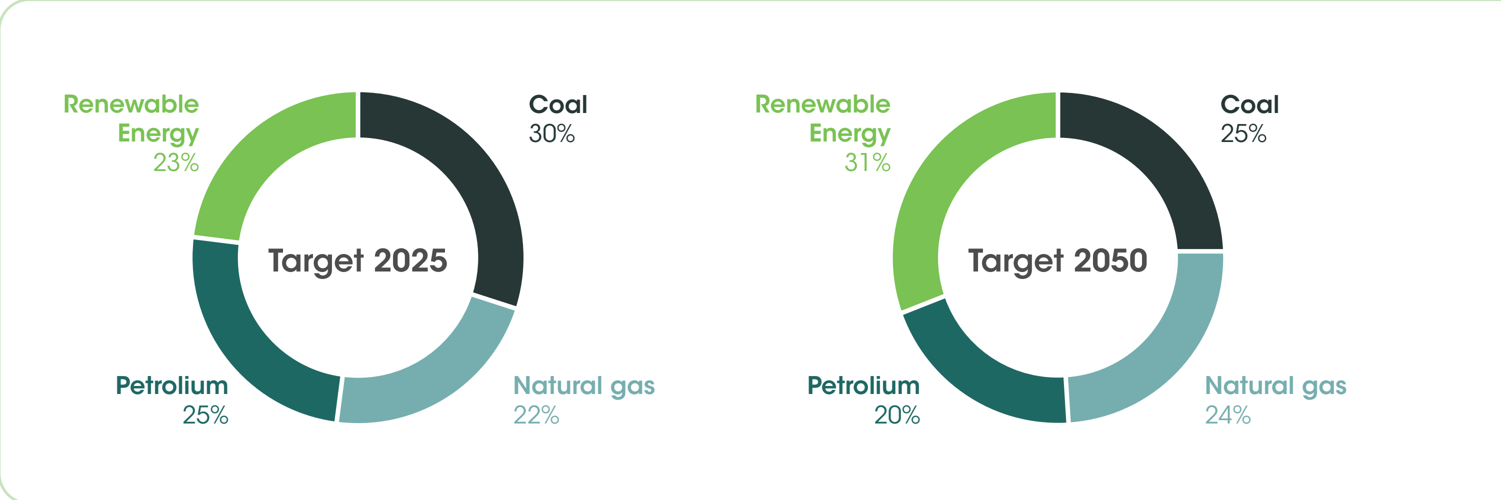
The industry and transport sectors consume approximately 67% of Indonesia's energy (see Figure 7) and provide concentrated nodes of energy demand where fuel substitutions should be facilitated in a move toward a low carbon economy.

FIGURE 7: Indonesia's energy mix and usage of conventional fossil fuels in 2017



Under current energy policies, coal consumption is projected to rise in order to meet growing demand for industry in Indonesia. Although many technical and economic challenges remain in substituting biomass for metallurgical coal, coal used in the cement making process is considered a substitutable demand due to its close heating value to biomass. Figure 8 presents Indonesia's energy mix targets for 2025 and 2050.

FIGURE 8: Indonesia's Energy mix targets for 2025 and 2050



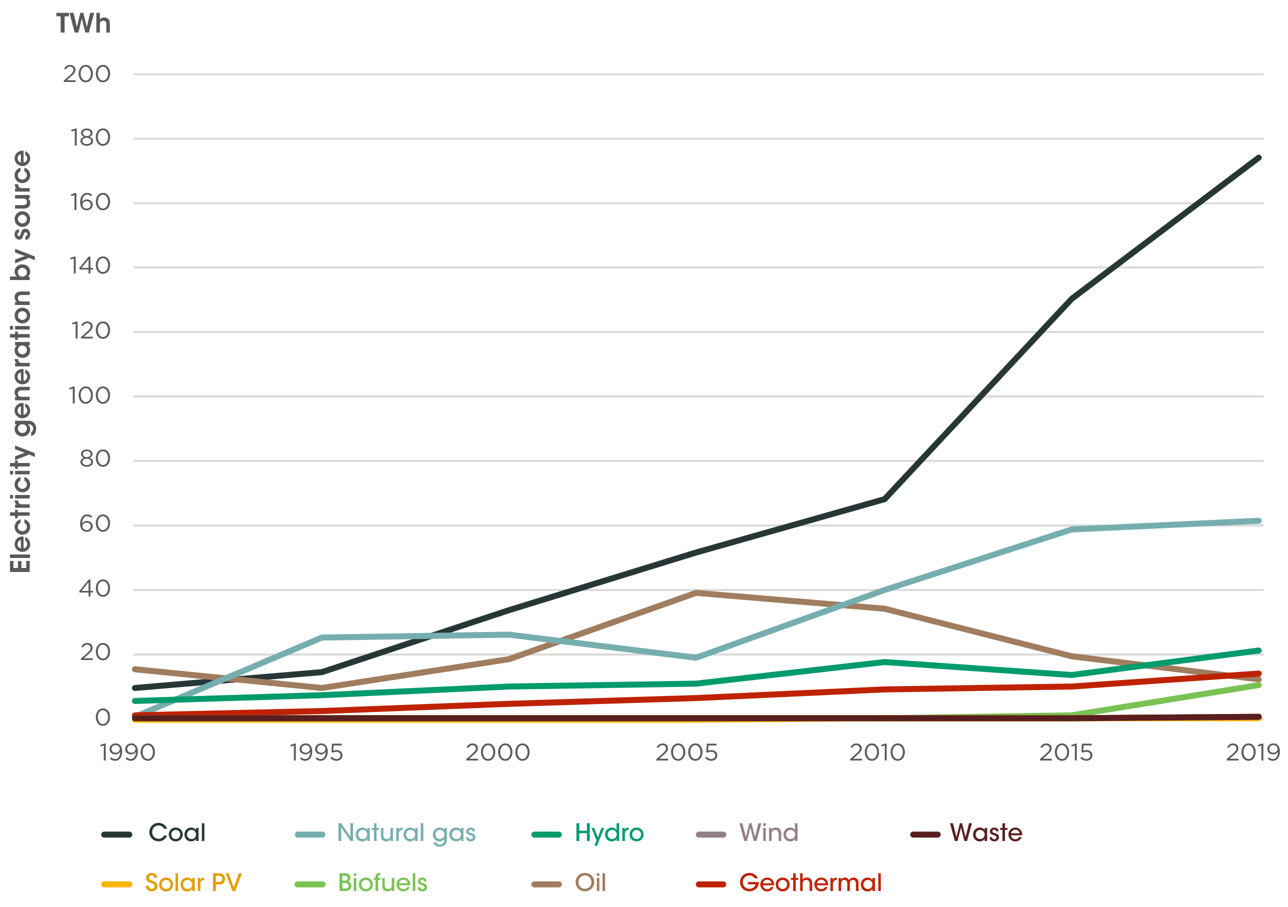
Source: IEA (2019)

Consumption of coal and natural gas has considerably increased in the last decade and is expected to grow further under current energy policies in Southeast Asia (IEA, 2019). While solar and wind are expected to play expanded roles in the power mix of the country, bioenergy can also be explored as a realistic option to aid a structural shift to clean energy by providing heat and baseload electricity supply without disrupting grid stability. The economic rationale for positioning biomass-based power generation as a substitute for coal and natural gas options while solar and wind power generation costs are rapidly declining is the fact that moderate modifications to existing facilities are required for switching fuels to biomass. Furthermore, there is the possibility that phased replacement of coal can be planned by adopting co-firing without risking existing facilities becoming stranded assets (Gent et al., 2017). The Government of Indonesia has initiated co-firing as part of an effort to achieve a mix of renewable energy and emissions reduction whilst keeping investment relatively low, as co-firing can be implemented in existing coal power plants. Currently, co-firing is only intended for the coal-fired power plants (114 plants at 52 locations) owned and operated by the state-owned entity Perusahaan Listrik Negara (PLN). Future expansion of the scheme is expected to include coal-fired power plants owned and operated by independent power producers (IPPs).

In addition, biomass-based combined heat and power (CHP) plants can provide not only clean electricity but also renewable heat if the supply can be harnessed to heat demand in surrounding areas, thus significantly improving overall energy output.

Figure 9 below presents Indonesia's sources of electricity generation from 1990 to 2019. In 2019, biofuels contributed approximately 11 terawatt hours (TWh), representing only 4% of the country's electricity generation. Coal dominates the electricity generation mix at 175 TWh, with natural gas, hydro and oil providing 62 TWh, 21 TWh and 12 TWh, respectively.

FIGURE 9: Sources of electricity generation in Indonesia, 1990–2019



Note: PV = photovoltaic
Source: IEA (2020)

In 2018, Indonesia enforced the mandatory use of diesel containing 20% locally-produced biofuel under the B20 Policy (Jaganathan, 2018). The policy sought to help reduce Indonesia's fuel import and production cost, as well as to cushion the impact on its economy of a currency crisis and higher oil prices (Jaganathan, 2018). Since its introduction in 2018, the B20 policy has achieved dramatic increases in biodiesel consumption, with further projected growth in consumption of 23% between 2021 and 2030 (Kondalamahanty and Raj, 2021). The Indonesian government increased the blending rate of biodiesel to 30% under the B30 Policy, starting from January 2020, to further reduce its fuel import bill and increase domestic palm oil consumption (Christina, 2019). The introduction of the B30 policy is expected to provide a boost to biodiesel consumption, with an estimated 8 billion litres of being consumed in Indonesia in 2020 (Reuters, 2020).

Bioenergy pathways and substitutable markets identified in Indonesia

By considering both supply and demand in Indonesia's energy mix, four bioenergy pathways are identified as the most likely bioenergy applications, as described below.

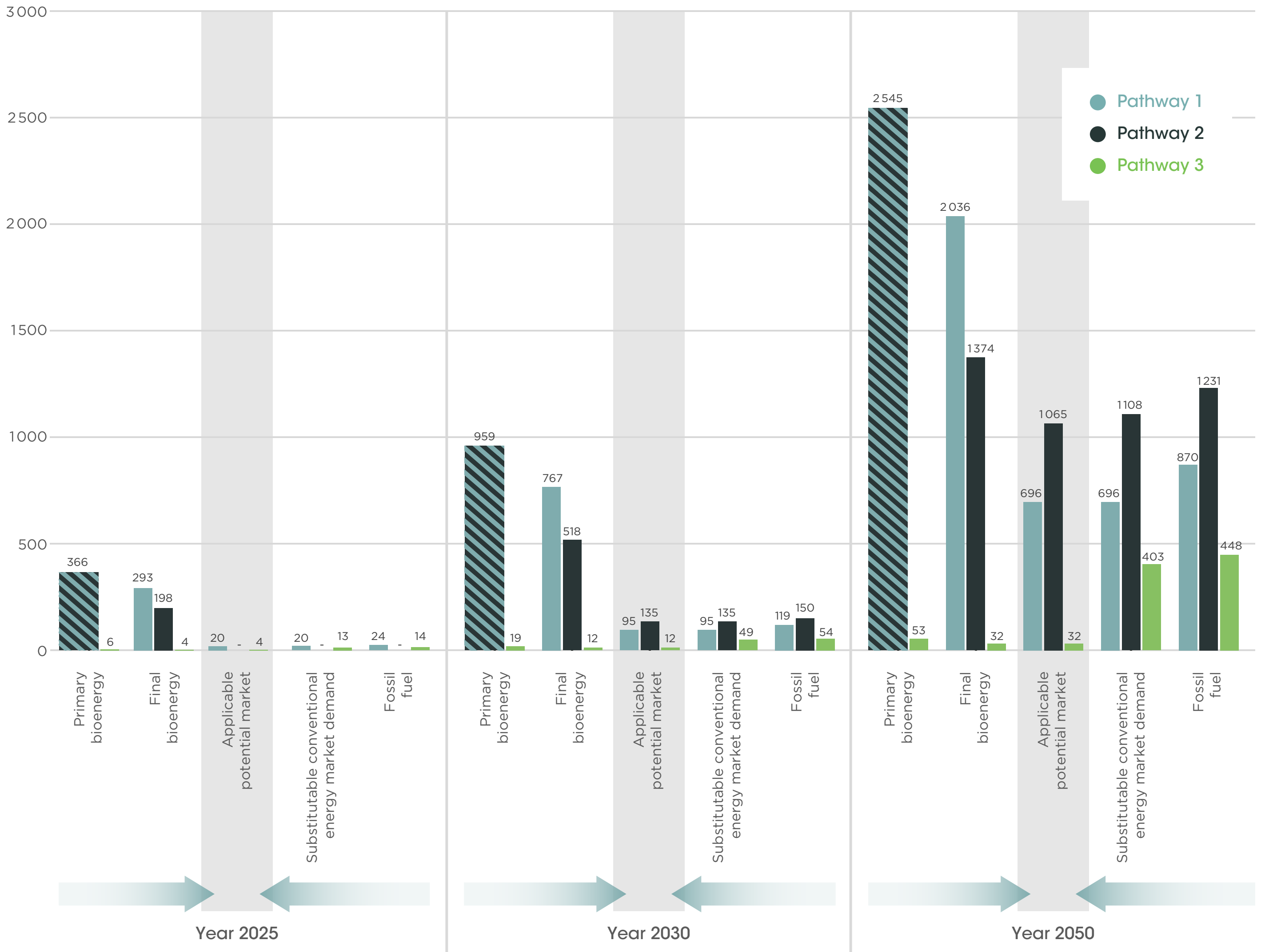
TABLE 12: Feedstock and processes identified for each bioenergy pathway, Indonesia

Type of feedstock	Type of process
Agricultural residues from major crops, rubber and acacia	Direct combustion for industrial heat generation
	Direct combustion for combined heat and power generation
Palm oil mill effluent (POME) and cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants

Substitutable markets for biomass have been estimated over three different horizons, namely 2025 (short-term), 2030 (medium-term) and 2050 (long-term).

From the bioenergy supply and demand outlined in this study, prospective bioenergy pathways have been mapped according to several of the most probable applications of biomass as a fuel source in Indonesia's energy mix. The total applicable potential market in Indonesia is estimated to be around 24 PJ in 2025, 242 PJ in 2030, and 1 783 PJ in 2050.

FIGURE 10: Bioenergy pathways in Indonesia (2025, 2030 and 2050) in PJ[14 15]



14 Note that the potential for agricultural residue is adjusted to ensure that it will not compete with the supply used for animal feed and animal bedding.

15 Note that the conventional fuel demand in 2050 is based on the current demand for conventional fuel with a growth rate similar to estimated energy demand growth.

Bioenergy pathway 1 (direct combustion for industrial heat generation) focuses on replacement of brown coal with biomass in heat boilers. Brown coal is mostly consumed in non-metallic minerals (e.g. cement), and the pulp and paper industry in Indonesia. In 2017, the total amount of brown coal consumed in the industry sector was over 330 PJ (IEA, 2020). Indonesia has a substantial coking coal consumption for iron and steel, and non-ferrous metals. Biomass at steel-making plants has been demonstrated but is still not widely commercialised in the region. Such sources of demand are selectively included in the mid- and long-term horizon assessments.

This study assumes that biomass can be used for co-firing with brown coal to produce heat in the short term and that 5% of brown coal can be replaced by 2025 with biomass in a retrofitted co-firing boiler during the initial pilot phase. The existing co-firing pilot projects in Indonesia now allow 1%–5% of biomass, with optimum performance with up to 3% biomass. By 2030 the co-firing ratio is set to increase to 15%, which is in line with the feasible and economic co-firing ratio. The cost of retrofitting will rise when the cofiring ratio exceeds 20%. Therefore, in the long term, we assume standalone biomass boilers will be deployed over time until 2050, which will then unlock further potential for biomass utilisation and increase the replacement ratio to 75%. The substitutable market is evaluated at 20 PJ, 95 PJ and 696 PJ by 2025, 2030 and 2050, respectively.

Bioenergy pathway 2 (direct combustion for combined heat and power generation) focuses on replacing coal with biomass in CHP plants. In Indonesia, most coal consumption is met by sub-bituminous coal except for coking coal in metal production, (IEA, 2017). Biomass can replace coal, which can then be used as the energy source for CHP plants, providing the highest overall conversion efficiency. For Indonesia, this pathway aims to replace coal consumption in industry used to produce heat and power, which totalled 861 PJ in 2017 or equivalent amount used in the power sector.

In the short term, this study assumes there will not be any CHP capacity built and completed by 2025. In the medium and long term, with new-build biomass CHP plants, this analysis assumes that 15% of coal fired heat boilers or power plants will be replaced by biomass-fuelled CHP plants in 2030, increasing to 75% in 2050. The substitutable market is evaluated at 135 and 1 065 PJ by 2030 and 2050, respectively.

Bioenergy pathway 3 (anaerobic digestion to generate biogas for both heat boilers and CHP plants) focuses on replacing natural gas with biogas in heat boilers in the short term and CHP plants in the medium and long term.

In 2017, 193 PJ of natural gas was used to produce heat in the industry sector – mainly in chemicals and petrochemicals – and a third of this was used to produce electricity in industry plants (IEA, 2020). For pathways 2 and 3, the demand for heat and power included in this analysis will be limited to only large industrial facilities – such as large refineries of petrochemical products, palm oil, and sugar industries or large industrial parks for downstream manufacturing and processing where the future heat demand is clustered and can be met by the gas-fired steam boilers or gas-fuelled CHP plants, with the electricity supply connected to power grids.

In the short term, this study assumes that 5% of the natural gas consumed in heat boilers can be replaced by biogas by 2025. In the medium and long term, with new-build biogas CHP plants, this analysis assumes that 15% of natural gas fired heat boilers will be replaced by biogas-fuelled CHP plants in 2030, increasing to 75% in 2050.

The substitutable market is evaluated at 13 PJ, 49 PJ and 403 PJ by 2025, 2030 and 2050, respectively. The analysis conducted as part of this study identifies that, in the short and medium term, biogas from POME and cassava pulp can act as a substitutable energy source for natural gas. However, due to limiting factors such as accessibility and collectability, biogas generated from POME and cassava pulp feedstock can only act as a substitutable energy source for 9% (32 PJ) of demand by 2050.

Economic assessment

For each bioenergy pathway, an economic assessment is provided, presenting the scale of socio-economic benefits that can be unlocked through successful implementation. Each pathway is compared with its substitutable market in order to determine the economic value that can be replaced by bioenergy. For instance:

- **Bioenergy pathway 1** (direct combustion for industrial heat generation) compares the economic costs and benefits of direct combustion of biomass pellets produced from residues of oil palm, rice, sugarcane, rubberwood and acacia against coal for cement kilns and other industrial process heat
- **Bioenergy pathway 2** (direct combustion for combined heat and power generation) compares the economic costs and benefits of direct combustion of biomass pellets produced from residues of oil palm, rice, sugarcane, rubberwood and acacia against coal for heat and power generation at CHP plants
- **Bioenergy pathway 3** (anaerobic digestion to generate biogas for both heat boilers and CHP plants) compares the economic costs and benefits of using biogas produced from the anaerobic digestion processes for POME and cassava pulp against natural gas for heat and power plant generation at CHP plants

A summary of findings from our bioenergy economics analysis is presented in the following dashboard and summary table:

FIGURE 11: Summary dashboard for all bioenergy pathways, Indonesia, 2050 (USD)

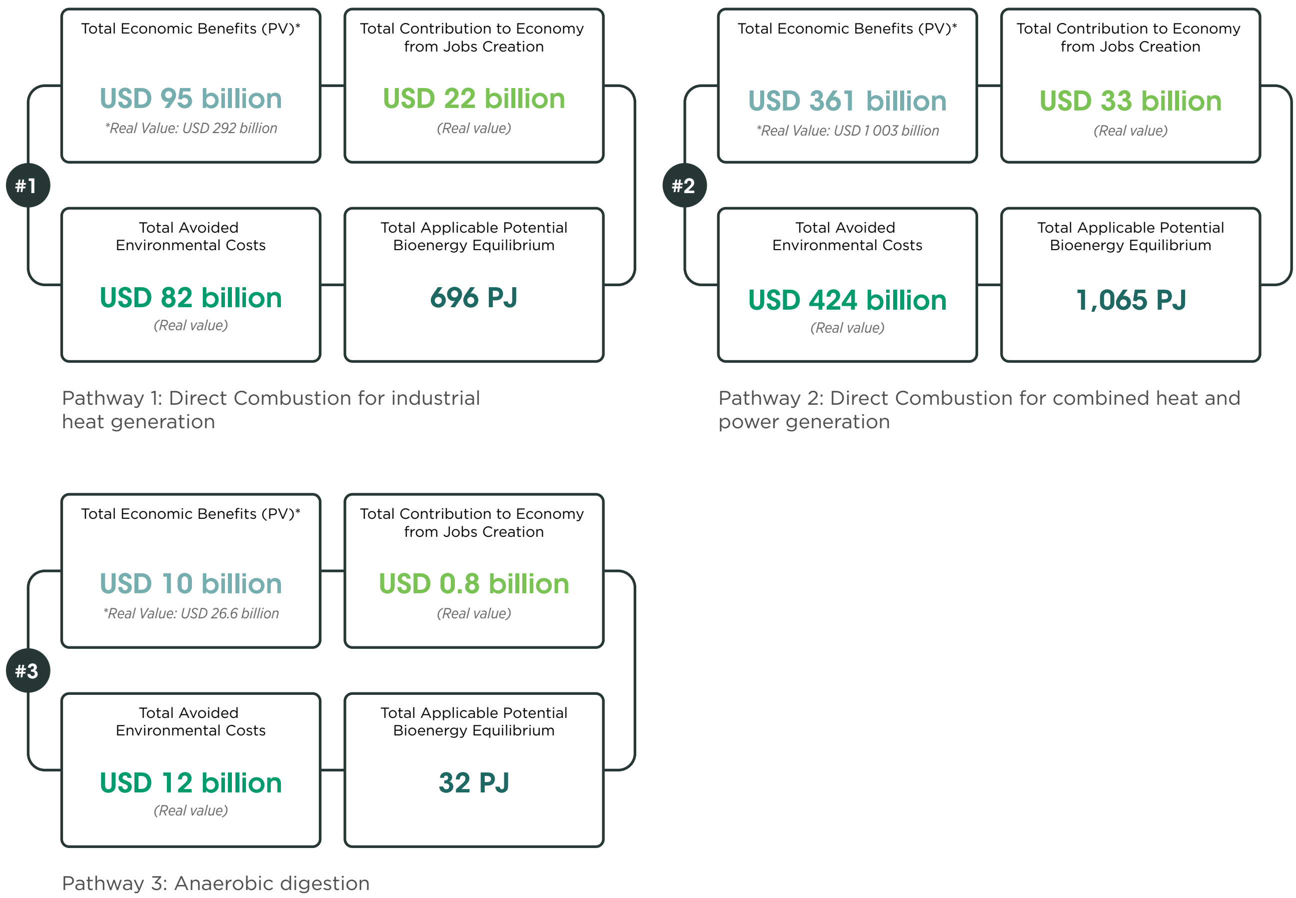


TABLE 13: Summary of findings for all bioenergy pathways, Indonesia

Type of feedstock	Type of process	Total applicable potential bioenergy equilibrium (2050)	BCR (2050)	Total net present value of economic benefits (NPV) in USD bn (2050)
Agricultural residues from major crops, rubber and acacia	Direct combustion for industrial heat generation	696 PJ	1.25	18.5
	Direct combustion for combined heat and power generation	1 065 PJ	1.24	70.6
Palm oil mill effluent (POME) and cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants	32 PJ	1.34	2.4

These three bioenergy pathways result in benefit-cost ratios (BCR) above 1 and in significant impacts on the economy of Indonesia, amounting to approximately USD 91.5 billion of net present value of socio-economic benefits in 2050, potential creating over 212 000 new resilient jobs and saving around 274 million tonnes of GHG emissions per year, corresponding to nearly 46% of the country's total GHG emissions excluding land-use change and forestry as of 2016 (WBG, 2021).

The identified socio-economic costs and benefits were evaluated in real value (USD million) for the years 2025, 2030 and 2050, and adjusted for economic inflation. The results for each bioenergy pathway shown below.

The bulk of socio-economic benefits to be derived from the pathways stem from:

- cost savings from construction;
- cost savings from avoided GHG emissions;
- benefits from resilient employment; and
- improvement of energy security.

FIGURE 12: Total cost and breakdown of benefits in USD million (real value), Indonesia – pathway 1

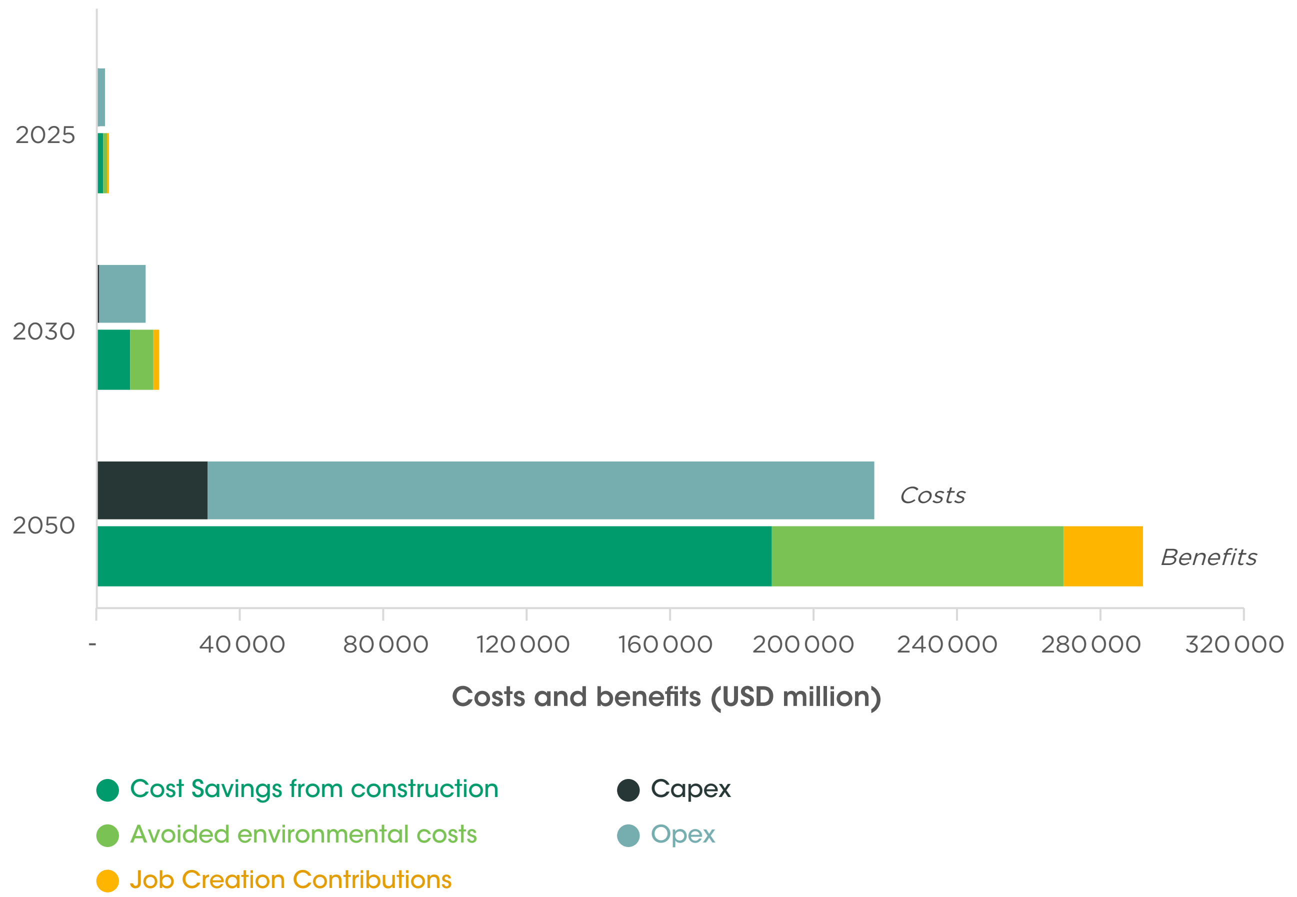


FIGURE 13: Total cost and breakdown of benefits in USD million (real value), Indonesia – pathway 2

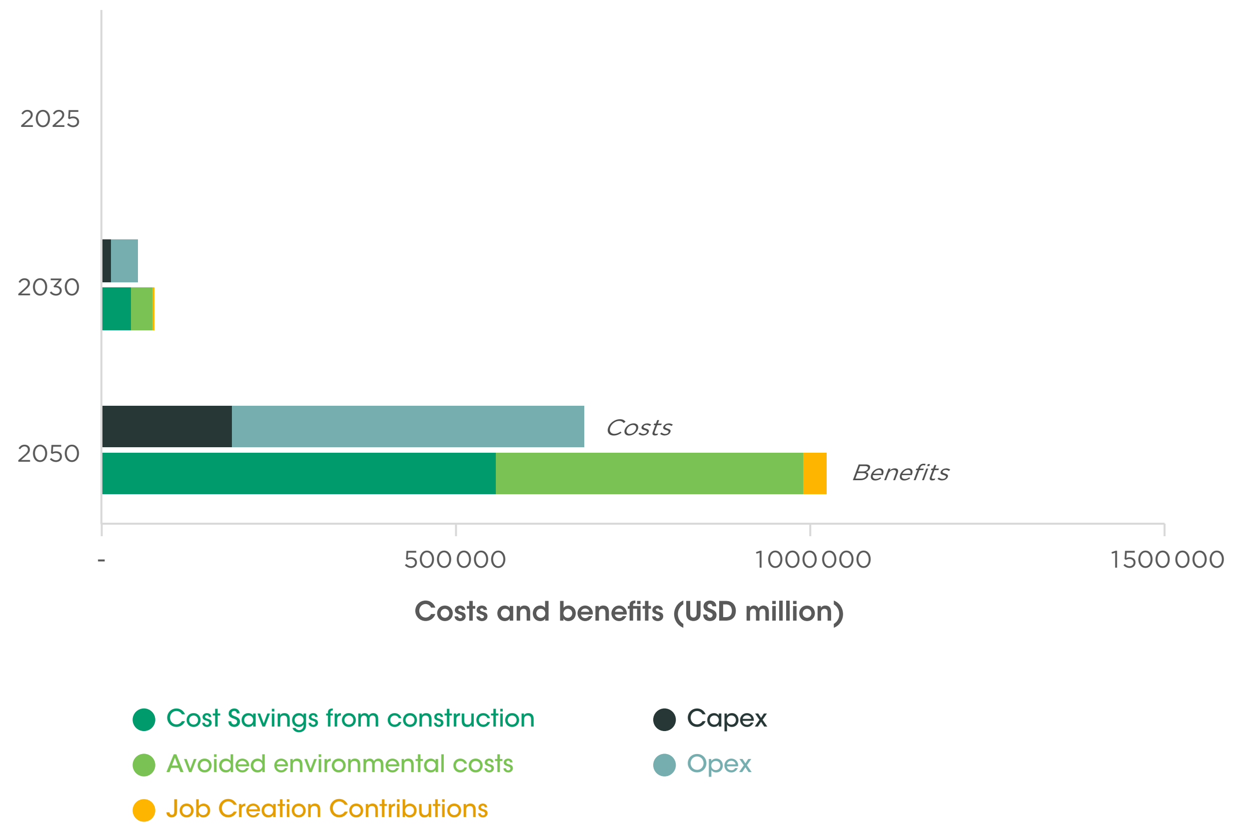
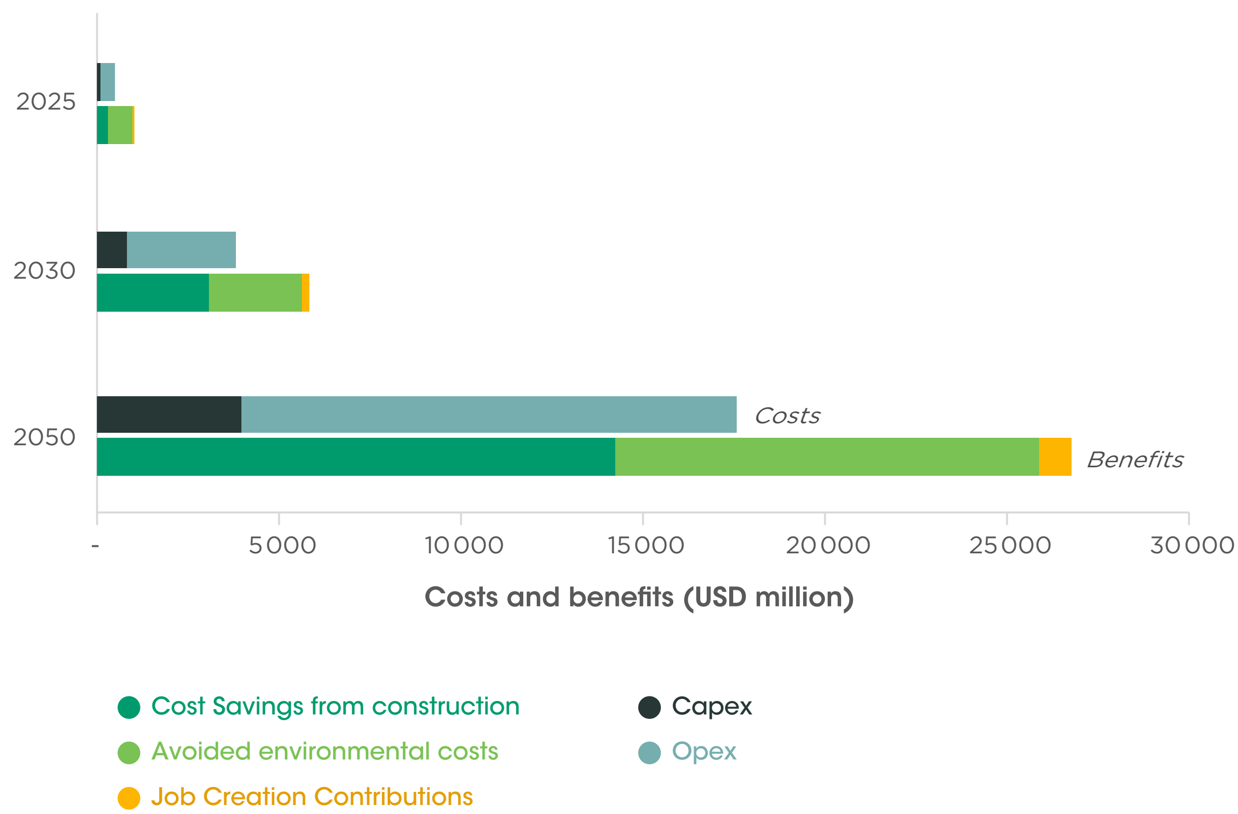


FIGURE 14: Total cost and breakdown of benefits in USD million (real value), Indonesia – pathway 3



Socio-economic benefits

I. COST SAVINGS FROM CONSTRUCTION

The figures below summarise potential cost savings from construction realised through implementation of the three bioenergy pathways. Cost savings from construction primarily includes an evaluation of the gigawatt equivalent (GWe) avoided from the cost to construct and operate a traditional fossil fuel plant. Note that the costs of constructing the biofuel plants is included in this study's cost analysis:

TABLE 14: Capacity of traditional fossil fuel plant saved, Indonesia

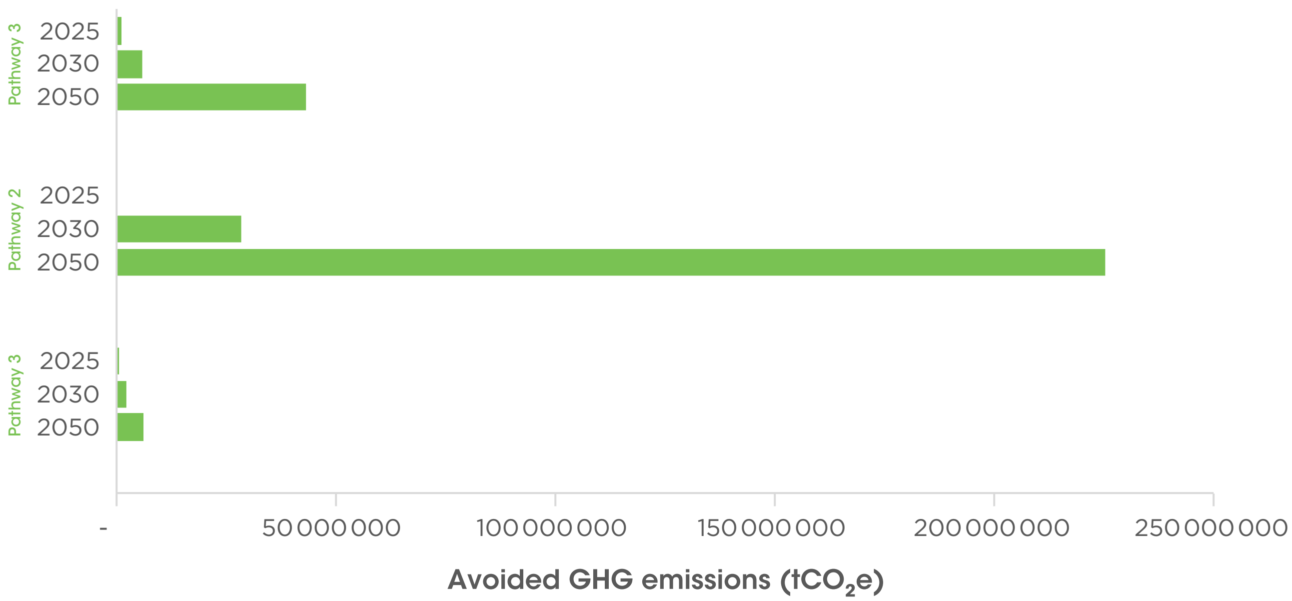
Capacity of traditional fossil fuel plant saved	2025	2030	2050
Capacity of industrial heating facilities saved (GWe)	0.8	3.8	27.6
Capacity of CHP / power plants saved (GWe)	0.1	5.8	43.3

II. COST SAVED IN AVOIDED GHG EMISSIONS

Further socio-economic benefits can be depicted through avoided GHG emissions, comparing biomass energy plants with traditional fossil fuel energy plants.

The potential GHG emissions avoided for each bioenergy pathway are presented below:

FIGURE 15: GHG emissions avoided in Indonesia



This represents GHG emission savings of approximately 43 million tCO_2e, 225 million tCO_2e, and 6.1 million tCO_2e for pathways 1, 2, and 3 by 2050, respectively.

Indonesia is one of the world's largest GHG emitters and has committed to reduce emissions by 29% from the business-as-usual scenario by 2030 – or by at least 41% with provision of international assistance under the 2015 Paris Climate Agreement framework (Jong, 2020). Indonesia needs to reduce its GHG emissions to below 551 million tonnes by 2030 and to below 128 million tonnes by 2050 to be within its fair-share range according to global 1.5°C IPCC scenarios (Climate Transparency, 2019). Although introducing these bioenergy pathways alone will not be enough for Indonesia to meet its commitments, the GHG emissions savings noted will facilitate this aim.

III. BENEFITS FROM RESILIENT EMPLOYMENT (NET JOB BENEFITS)

Estimating the number of resilient jobs created through the implementation of these bioenergy pathways is a useful measure to gauge socio-economic benefits. By 2050, implementing these bioenergy pathways provides resilient jobs for approximately 212 000 Indonesians.[16]

The figures below summarise the resilient jobs created through the implementation of the bioenergy pathways in the farming and non-farming sectors:

FIGURE 16: Estimated number of resilient jobs created, Indonesia – pathway 1

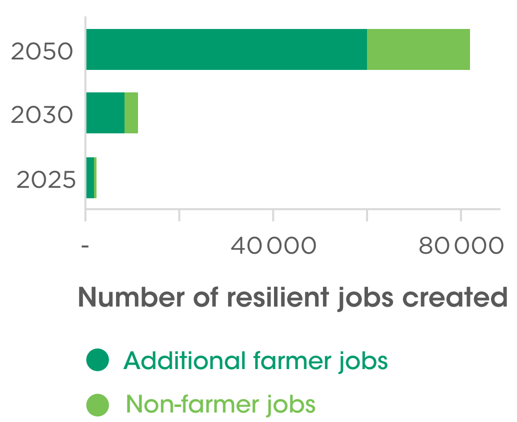
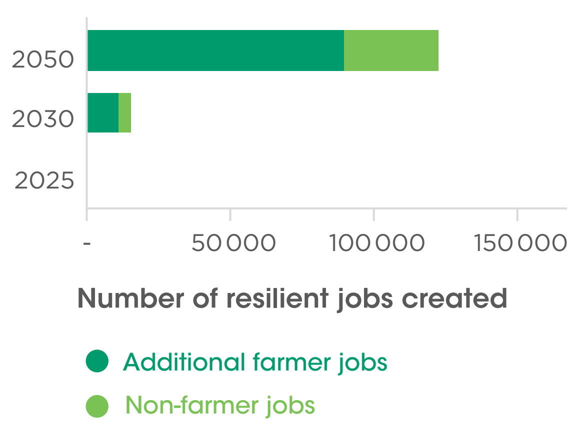
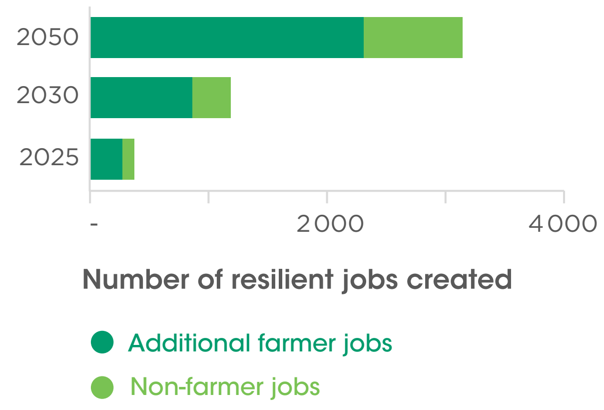


FIGURE 17: Estimated number of resilient jobs created, Indonesia – pathway 2



16 Benefits are calculated as net job benefits, meaning the figure accounts for lost jobs in the coal, oil and gas industries.

FIGURE 18: Estimated number of resilient job created, Indonesia – pathway 3



IV. IMPROVEMENTS IN ENERGY SECURITY

As Indonesia is a net exporter of coal and natural gas, the improvements on energy security through implementation of the three bioenergy pathways were not assessed in this analysis. However, the implementation of bioenergy projects will help countries mitigate the risk of energy supply shortages and their associated costs.

Summary of Findings

The average annual cost required to realise the three bioenergy pathways is estimated to be around USD 12.5 billion through 2050. In this study, costs include capital expenditure, operations and maintenance costs. On the other hand, the average annual socio-economic benefits achieved through the implementation of the pathways would exceed average annual economic costs by USD 3 billion through 2050, resulting in net positive gains.

Utilising the analysis above, the consequent total socio-economic benefits for each bioenergy pathway are presented in ENPV and calculated as a BCR:

TABLE 15 : Socio-economic outcomes arising for potential bioenergy pathways, Indonesia

Bioenergy pathways	Present value of total economic costs for each bioenergy pathway (in USD million)			Economic net present value of total socio-economic benefits for each bioenergy pathway (in USD million)			Benefit-cost ratio for each bioenergy pathway		
	2025	2030	2050	2025	2030	2050	2025	2030	2050
Bioenergy pathway 1 direct combustion for industrial heat generation	715	4 000	76 936	105	587	18 469	1.15	1.15	1.25
Bioenergy pathway 2 direct combustion for combined heat and power generation	-	21 250	290 751	-	5 162	70 627	-	1.24	1.24
Bioenergy pathway 3 anaerobic digestion to generate biogas for both heat boilers and CHP plants	184	1 541	7 106	84	527	2 428	1.46	1.34	1.34
Total	**898**	**26 791**	**374 792**	**189**	**6 275**	**91 524**			

The key observations from this assessment are:

- BCR values for all bioenergy pathways are greater than 1.0, thus all bioenergy pathways would deliver strong ENPV of socio-economic benefits to Indonesia; amounting to over USD 91.5 bn in net benefits in 2050.
- Bioenergy pathway 2 offers the most significant potential socio-economic impact (ENPV of ~USD 70.6 bn in 2050). This result suggests that Indonesia can consider phasing out energy supplied by fossil fuels for the industry and power sector in an economically viable manner by taking advantage of the benefits derived from this pathway.
- All bioenergy pathways identified for the respective biomass feedstocks present positive socio-economic benefits to Indonesia. All pathways have merits from their implementation and, based on the economic analysis conducted as part of this study, represent commercially viable routes for converting these select biomass feedstocks to biofuel.

Key barriers and interventions

This study reviewed Indonesia's current bioenergy framework through political, economic, social, environmental, technological, legal and financial (PESTEL&F) parameters, identifying key barriers to implementing the bioenergy pathways identified above, and the potential intervening actions required to mitigate the barriers and unlock each pathway's potential socio-economic benefits.

Key barrier 1: Low policy incentive to decarbonise industrial process heat

Much of Indonesia's GHG emissions stem from the industrial heat generation process through the combustion of coal. To date, policy incentives are still not strong enough to decarbonise this process. This barrier was identified by analysing Indonesia's bioenergy market through the legal parameter of the PESTEL&F analysis.

There are several approaches that Indonesia can take to begin building a policy framework that seeks to reduce GHG emissions from the industrial sector. Firstly, carbon trading regulations could be an option for Indonesia – namely the current drafting of the Presidential regulations on carbon trading; this offers an opportunity to aid progress towards meeting an enhanced NDC target. The regulation has plans for carbon trading, carbon trading offset, and a commodity market (Climate Transparency, 2019).

Secondly, Indonesia can seek to build a policy framework that provides private and public institutions with incentives to develop decarbonisation measures in the following areas (McKinsey & Company, 2018):

- **Electrification of heat:** emissions from the use of fossil fuels to generate heat can be abated by switching to furnaces, boilers and heat pumps that run on zero-carbon electricity.
- **Biomass usage:** sustainably produced biomass can be used in place of some fuels and feedstocks; with co-firing being a realistic option for accelerating fuel switching.
- **Palm oil residues:** mobilising palm oil residues and waste such as EFB, PKS, old trunks and POME for bioenergy feedstock will not only reduce GHG emissions but boost the overall sustainability of the oil palm industry.
- **Hydrogen usage**: emissions from the consumption of fossil fuel for heat and emissions from certain feedstocks can be abated by replacing them with zero-carbon hydrogen.
- **Other innovations:** Indonesia can seek to create more incentives for private institutions to retrofit their facilities with commercially viable technologies that will allow existing plants to use biomass feedstock for the heat generation process.
- **Demand-side measures:** decreasing the demand for industrial products, which in turn leads to lower production and GHG emissions.
- **Energy-efficiency improvements:** increasing energy efficiency can economically cut fuel consumption for energy use by 15%-20% across sectors.

Key barrier 2: Higher cost of converting biomass to energy compared with traditional fuel sources

Production of commercially viable solid, liquid and gaseous biofuels will facilitate uptake of the bioenergy pathways proposed in this report. As shown by Indonesia's B20 and B30 policies, for example, reducing the cost difference between biofuel and traditional fuel sources correlates with an increase in biofuel consumption (Jaganathan, 2018; Kondalamahanty and Raj, 2021) :

- Fossil fuel subsidies in Indonesia, which lower fossil fuel costs but do not have a direct impact on increasing biofuel costs, make solid biofuel feedstock less attractive.
- To increase commercial viability and reduce the cost of producing biofuels, the Indonesian government can take three actions:
  - introduce a favourable regulatory framework;
  - redirect fossil fuel subsidies to clean energy; and/or
  - increase spending on R&D to further reduce the cost of conversion from biomass to energy.

Key barrier 3: Sustainability assurance and confidence for oil palm biomass

Palm oil is a potential biomass feedstock that has negative connotations. With or without sustainability assurance, a scaling up of the deployment of palm oil and associated oil palm biomass for the renewable energy market must also deal with reputational risks for both business operators and investors. Nevertheless, there are several ways to harness the vast, yet untapped bioenergy potential of the palm oil sector by addressing the following challenges:

- Given the relatively short history of palm oil production, there are still many unknown impacts on the environment caused by oil palm cultivation. For example, a research project carried out by the Japan International Research Centre for Agricultural Sciences (JIRCAS) presented preliminary findings indicating that feeding palm oil residues back into farms as organic fertiliser – a widely adopted practice on the ground – may have a negative impact on the environment through CH4 emissions in the process of decomposition from teeming termites as well as nitrogen starvation leading to over-fertilisation and resultant N_2O emissions.
- As more scientific evidence is accumulated, farming practices must be constantly updated to improve the sustainability standards of plantation management. However, farmers are generally not adaptive to such changes. Bringing oil palm residues such as OPT and EFB out of the farm as feedstock for bioenergy requires a breakthrough in cultural barriers and a behavioural change among farmers. Research organisations should play a critical role in not only disseminating scientific knowledge but also prompting farmers to adapt to up-to-date scientific evidence.

- Third-party certification schemes such as Malaysian Palm Oil (MSPO) and Indonesian Sustainable Palm Oil (ISPO) will play a central role in providing sustainability assurance. These schemes should also incorporate handling of oil palm residues and by-products in their sustainability standards. All oil palm growers and millers in the country must comply with mandatory ISPO certification. This mandatory requirement was implemented to address environmental issues in 2011. The credibility of ISPO should be further raised by implementing its mandatory processes properly, including among small holders.
- The bioenergy pathway identified in this study utilising POME as feedstock for CHP plants faces a challenge in terms of the distribution of biogas produced, owing to its unfavourable grid access. One possible alternative for using the biogas produced from POME is compressed biogas that can be injected into automobiles for transport fuels, as demonstrated by Osaka Gas Co., Ltd. in Thailand (Osaka Gas, 2017) . The use of biogas for transport fuels is still in its development stage in Southeast Asia but can be further explored in the future.

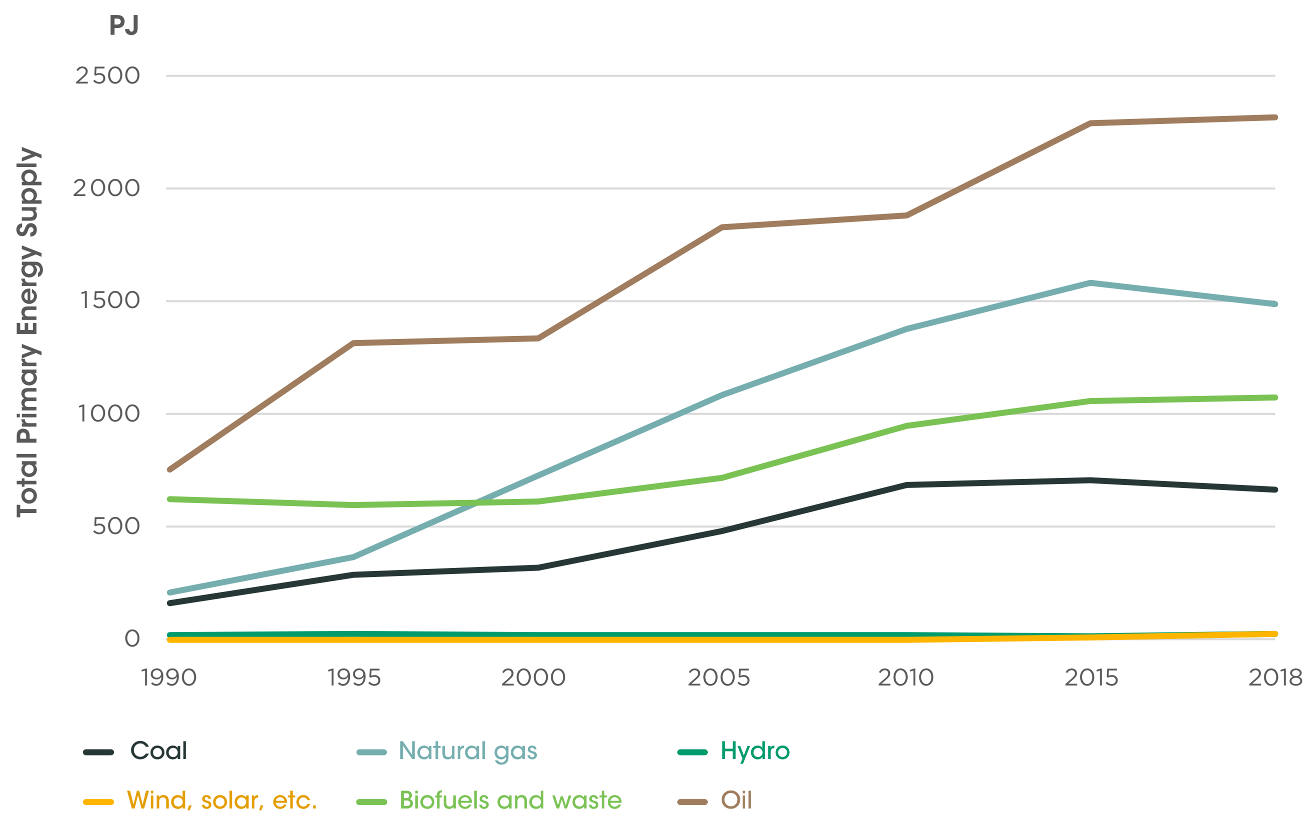
b. Thailand

Significant socio-economic benefits can be unlocked in Thailand by utilising the biomass feedstock produced from its large agricultural industry.

Thailand, located at the centre of the Indochinese Peninsula, is one of Asia's most populous countries and has a land area of 51 million ha, comprising 22 million ha of arable land and 20 million ha of forest (FAO, 2020b). Thailand has a thriving agricultural sector and is a major exporter of rice.

As presented in Figure 19, below, bioenergy is the largest energy source among renewables in Thailand, with a primary supply amounting to 1 074 PJ in 2018. Bioenergy is the third major energy source in Thailand, and is used for cooking and process heating in the residential and manufacturing sectors (Papong, et al., 2004). The supply of bioenergy has been increasing since 2000, although consumption of fossil fuels has also seen growth or remained consistent, as Thailand has constructed new power plants to meet rising electricity demands in rural areas.

FIGURE 19: Total primary energy supply in Thailand, 1990–2018



Source: IEA (2020)

While its demand for energy continues to grow, Thailand risks relying more on fossil fuels such as coal, natural gas and oil in its energy mix. To set a course for climate compatible pathways, it is of critical importance to reverse this trend and embark on an energy transition in which bioenergy plays an essential role.

Bioenergy pathways are presented below. They include the identification of potential biomass feedstock, types of biofuel conversion process and potential final applications, having been identified using the four push and pull factors outlined in Section 2.

Bioenergy pathways

Identifying available biomass feedstocks in Thailand

I. AGRICULTURAL RESIDUES, RUBBER AND TEAK

Thailand has a thriving agricultural sector that contributed approximately 9% of total GDP in 2020 (WBG, 2021) from 16.8 million ha of arable land (WBG, 2021). Thailand is a major exporter of sugar and palm oil, pineapples, rice, mangoes and coconut (FAOSTAT, 2021). Of these, the three agricultural crops with the largest potential for scaling residue-derived bioenergy are sugar rice and palm oil. These residues include sugarcane bagasse, tops and leaves, rice straw, rice husks, palm kernel shell, empty fruit bunches and old trunks.

Forestry activities in Thailand produced over 14.6 million m^3 of industrial roundwood for sawn timber, plywood, pulp and other fibre materials in 2019, and another 18.4 million m^3 of wood fuel was produced mainly for traditional cooking (FAOSTAT, 2021). While a large number of residues and by-products are generated at logging sites and through processing roundwood to lumber – such as tops, branch, bark, sawdust, listing and leftovers – this study focuses on woody biomass that can be sourced from plantations, as more analysis would be needed to assess whether forests are managed sustainably. The major plantations in Thailand are natural rubber and teak, spanning 3.73 million ha (Reuters, 2019) and 1.8 million ha (Sumantakul, 2008), respectively.

Thailand is the world's top producer and exporter of natural rubber, accounting for up to 40% of global supply. As explained in the section on Indonesia, processing residues of rubberwood has the potential to be deployed as bioenergy feedstock. In addition, Thailand's cabinet approved a 20-year plan in 2019 to slash rubber plantations by 21% nationwide (Reuters, 2019) from 3.73 million ha to 2.94 million ha, and increase the value of rubber exports by more than threefold. This could create a window of opportunity for Thailand to integrate bioenergy feedstock production in the rubberwood value chain.

Teak trees can be cut down every 15–20 years for building materials and furniture. In the teak tree truck processing, there is waste from cutting that has not been fully utilised which can be used to produce wood pellets for bioenergy feedstock (Pramono et al., 2011).

II. SUGARCANE MOLASSES, AND CASSAVA ROOTS AND STARCH

Sugarcane molasses is a viscous, dark, sugar-rich by-product of sugar extraction from sugarcane and can be used for bioethanol production. As Thailand's status of one of the world's leading exporting producers of sugarcane, a significant amount of by-product is produced. In 2019–2020, the production volume of sugarcane in Thailand was estimated to be around 127 million tonnes (Shafiq, Rehman and Santella, 2020) .

One metric tonne of sugarcane is capable of producing approximately 46 kg of molasses. Before the introduction of bioethanol feedstock, one third of molasses produced in Thailand was exported while the other two thirds were used as an additive in animal feed or disposed of on-site. After the introduction of molasses in ethanol production in 2008, approximately 78% of molasses in Thailand was used domestically to produce bioethanol (Russell and Frymier, 2012).

Cassava starch and chips are also good feedstocks for ethanol production. Currently, there are 11 Cassava ethanol plants in Thailand with a production capacity of over 2.5 million litres of ethanol per day (Hiangrat, 2019).

III. CASSAVA PULP

Thailand is the third largest cassava producer in the world (FAOSTAT, 2021) and the annual production of fresh cassava roots in Thailand is around 30 million tonnes. The total area of cassava plantations in Thailand in 2016 was about 14 000 km^2 (Thai Tapioca Starch Association, 2016). Considerable cassava production and processing across the entire country leads to large volumes of by-products.

Cassava pulp is a solid waste by-product during the starch production process. It has a high starch content (50%–60% dry basis), causing an environmental problem with disposal (Sriroth, Chollakup and Chotineeranat, 2000).

TABLE 16: Thailand's potential biomass energy sources – selected, available bioenergy feedstock

Type of feedstock	Quantity available (million tonnes)		
	2025	2030	2050
Sugarcane bagasse, tops and leaves	22.8	24.1	25.6
Rice husks, rice straw	21.6	22.8	24.3
Palm oil residues (PKS, EFB, old trunk)	12.3	13.0	13.8
Rubber	6.3	6.7	7.1
Teak	1.7	1.8	1.9

Cassava pulp	8.0	8.5	9.0
Sugarcane molasses	7.0 (Ethanol: 1.8 billion litres)	7.4 (Ethanol: 1.9 billion litres)	7.9 (Ethanol: 2.0 billion litres)
Cassava roots and starch	22.7 (Ethanol: 4.2 billion litres)	23.9 (Ethanol: 4.5 billion litres)	25.4 (Ethanol: 4.8 billion litres)
Total	**102.5**	**108.2**	**115.0**

Source: IRENA (2017a)[17]

The year-on-year increase in quantity available is due to an assumed growth rate of 1.1% from 2025 to 2030 and 0.3% from 2030 to 2050. Yield increase can be made possible by adopting new farming technologies such as mechanisation, cultivar improvement, precision agriculture as well as digital applications for monitoring and weather forecasting. Throughout this period, no land use change would occur, with a view to halting deforestation, and residue-to-crop production ratios remain constant.

It is worth noting that the residues used for other end-uses, such as animal feed, animal bedding, and rubber and teak for timber and furniture are all deducted from the total quantity available.

Identifying collectible biomass feedstocks in Thailand

As is the case also in Indonesia, the collection of bioenergy feedstocks faces several logistical challenges owing to their decentralised location, which acts as a barrier that results in some residues being left uncollected and untreated.

As biomass feedstock becomes gradually available over time, the collectible quantity also increases. This study assumes the collection ratio for applicable feedstock[18] to increase from 10% in 2025 to 30% in 2030 and further to 75% in 2050 for agricultural residue, and 30%, 50%, and 90% in 2025, 2030 and 2050, respectively, for woody biomass. Finally, this study assumes the feedstock collection ratio to increase from 70% in 2025 to 80% in 2030 and 90% in 2050 for sugarcane molasses and 20%, 35%, and 50% in 2025, 2030 and 2050, respectively, for cassava roots and starch. (see Table 17 below).

17 The quantity available for woody biomass provided in the IRENA report, Biofuel Potential in Southeast Asia, is estimated based on the annual woody biomass increment multiplied by energy wood share. The energy share of total woody biomass is 40% for lumber and furniture wood. The quantity available for harvest residues is limited to 25% to ensure soil quality and biodiversity.

18 The applicable feedstock excludes conventional use of the residues and cassava roots for animal feed and bedding, as well as rubber and teak for timber and furniture.

TABLE 17: Thailand's potential biomass energy sources – selected, collectible bioenergy feedstock [19]

Type of feedstock	Quantity collectible for bioenergy feedstock (million tonnes)		
	2025	**2030**	**2050**
Sugarcane bagasse, tops and leaves	2.3	7.2	19.2
Rice husks, rice straw	2.2	6.9	18.2
Palm oil residues (PKS, EFB, old trunk)	1.2	3.9	10.4
Rubber	1.9	3.3	6.4
Teak	0.5	0.9	1.7
Cassava pulp	0.8	2.5	6.8
Sugarcane molasses	5.6 (Ethanol: 1.5 billion litres)	6.3 (Ethanol: 1.6 billion litres)	7.1 (Ethanol: 1.8 billion litres)
Cassava roots and starch	4.5 (Ethanol: 0.9 billion litres)	7.2 (Ethanol: 1.4 billion litres)	12.7 (Ethanol: 2.4 billion litres)
Total	**19.0**	**38.3**	**82.4**

The increasing quantity of biomass feedstock available over each of the horizons studied directly correlates to an increasing amount of biomass feedstock collectible. Other factors that contribute to this increase include:

- improvements in logistics management;
- improvements in stock-pile management; and
- improvements in surrounding infrastructure.

The biomass feedstock collectible is converted to PJ in the table below and presented as estimated potential primary bioenergy supply Thailand would have available for each identified biomass feedstock. Corresponding bioenergy pathways are also presented.

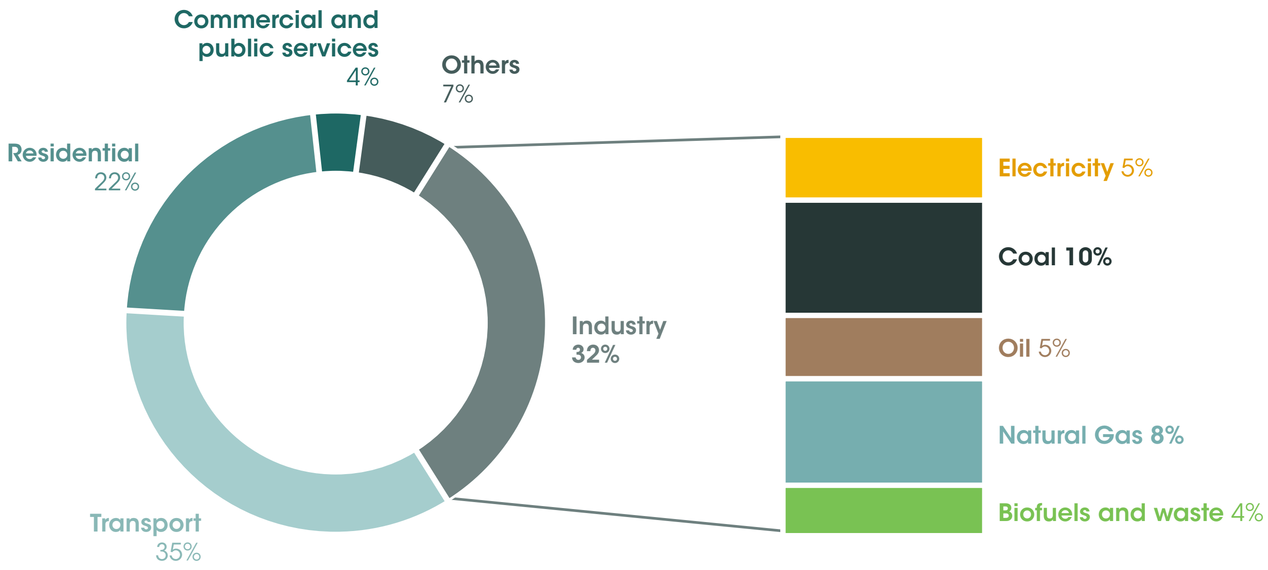
19 Due to lack of available data on how many tonnes of each biomass feedstock is already used as an energy source, this study assumes that all biomass feedstock analysed in this report are not utilised today and that the collection ratio of agricultural residues and woody biomass will increase over time.

TABLE 18: Thailand's potential primary bioenergy supply – selected, collectible bioenergy feedstock

Type of feedstock	Primary bioenergy supply (PJ)		
	2025	2030	2050
Sugarcane bagasse, tops and leaves	34.2	108.3	287.5
Rice husks, rice straw	32.4	102.8	272.9
Palm oil residues (PKS, EFB, old trunk)	18.5	58.6	155.5
Rubber	36.1	63.6	121.6
Teak	9.6	16.9	32.3
Cassava pulp	1.0	3.2	10.1
Sugarcane molasses	34.1	38.3	43.0
Cassava roots and starch	19.9	31.6	55.9
Total	**185.8**	**423.3**	**978.8**

Thailand's energy mix

FIGURE 20: Thailand's energy mix and use of conventional fossil fuels in 2017



As the final step in mapping bioenergy pathways, the most substitutable end-use markets for bioenergy penetration in Thailand are analysed.

The most probable application for bioenergy in Thailand is within the industry and transport sectors as substitutes for conventional fossil fuels. These sectors consume approximately 58% of Thailand's energy (see Figure 20) and provide concentrated nodes of energy demand where fuel substitutions should be facilitated in a move toward a low carbon economy. Under current energy policies, total consumption of fossil fuels is expected to rise in order to meet growing demand from the industry and transport sectors in Thailand, although total consumption of biofuels is also expected to increase as part of Thailand's energy mix (IEA, 2020).

Coal consumption is expected to rise in order to meet growing demand for the industry sector in Thailand. Although a lot of technical and economic challenges remain for biomass to be utilised as a substitute for metallurgical coal, brown coal used in the cement making process may be considered a substitutable demand due to its close heating value to biomass.

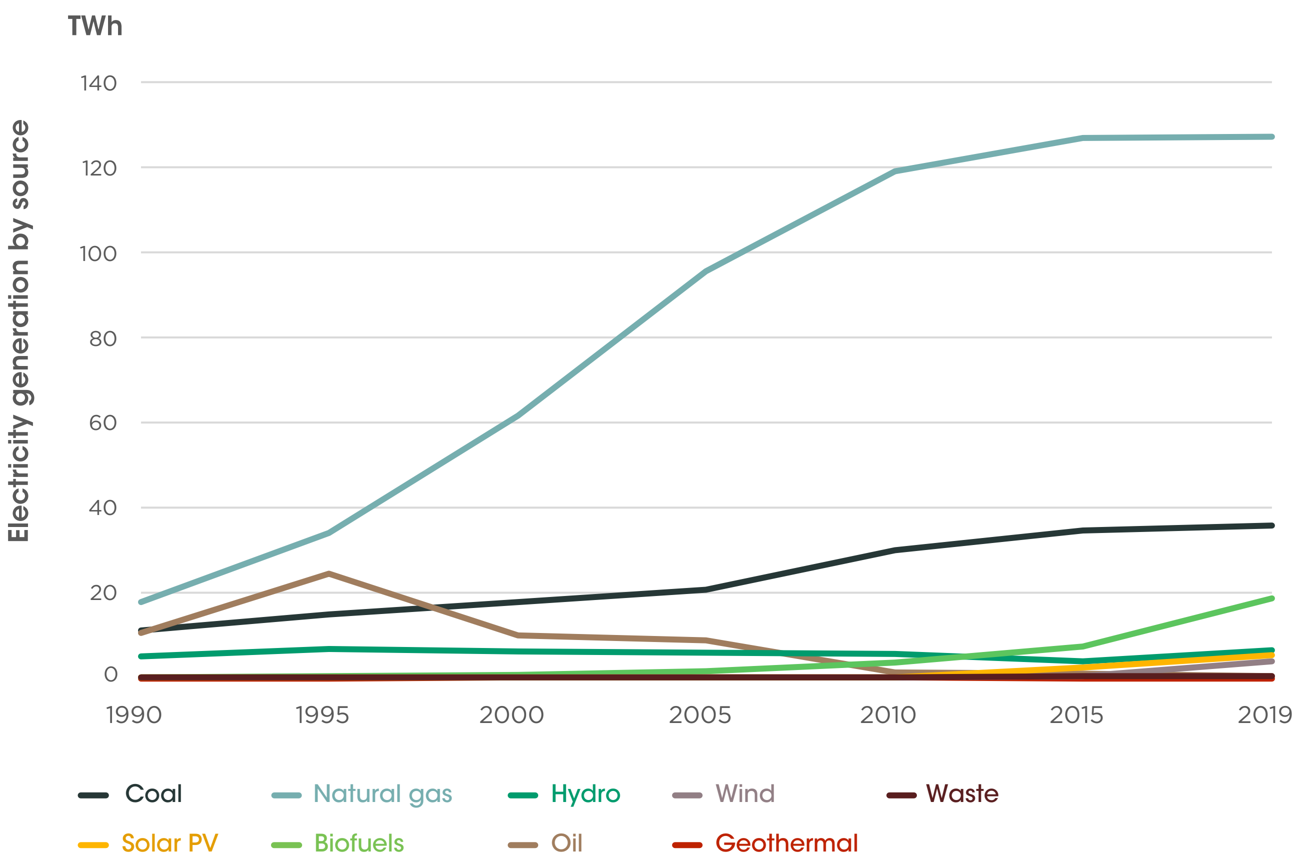
Consumption of coal and natural gas for electricity generation has increased considerably in the last decade and is expected to further grow under the current energy policies (IEA, 2019). Figure 21 presents Thailand's sources of electricity generation from 1990 to 2019.

In 2019, biofuels contributed approximately 19 TWh, representing only 10% of the country's electricity generation. Natural gas dominates the electricity generation mix at 127 TWh, with coal, hydro and oil providing 36 TWh, 6 TWh, and 0.2 TWh, respectively.

While solar and wind are expected to play an expanded role in the power mix of the country (Setboonsarng and Wongcha-um, 2018), biomass power generation should also be explored as a realistic option to support a structural shift to clean electricity. The economic rationale for positioning biomass-based power generation as a substitute for coal and natural gas is the fact that existing facilities can be retrofitted to utilise biomass feedstock. While retrofitting existing plants will incur costs, the ability to leverage existing plants in lieu of constructing new facilities provides a pathway for adopting co-firing whilst mitigating the risk of existing facilities becoming stranded assets (Gent et al., 2017).

Biomass-based CHP plants can provide not only clean electricity but also renewable heat to meet demand in surrounding areas, thus significantly improving overall energy efficiency.

FIGURE 21: Sources of electricity generation in Thailand, 1990–2019



Source: IEA (2020)

Under the Thailand Power Development Plan (PDP), the Thai government aims to increase electricity generation from biomass from 2 452 MW in 2014 to 5 570MW by 2036 (EGAT, 2009). The Thai Alternative Energy Development Plan (AEDP) has also set ambitious targets for heat generation from renewable energy, targeting an increase from 242 PJ in 2014 to 1 050 PJ in 2036 (Netherlands Embassy in Bangkok, 2016).

The Thai government aims to reach its ambitious targets by introducing various incentives and policies. The latest feed-in-tariff scheme (FiT) supports project development for the next 20 years by providing attractive rates for electricity produced from biomass.

The Thai government is also promoting the use of gasohol (ethanol–gasoline blends) through price incentives and an excise tax reduction for cars compatible with E20 (20% ethanol and 80% gasoline) and E85 (85% ethanol and 15% gasoline) gasohol under the government's ethanol policy, first introduced in the early 2000s (Prasertsri, Hanikornpradit and Mullis, 2020). The incentives seek to promote the use bioethanol as a fuel source for the transport industry, with noted shifts in the number of E85 cars on the road and wider distribution already noted in 2014 (S&P Global, 2014).

Bioenergy pathways and substitutable markets identified in Thailand

By considering both supply and demand in Thailand's energy mix, four bioenergy pathways are identified as the most probable bioenergy applications as described below.

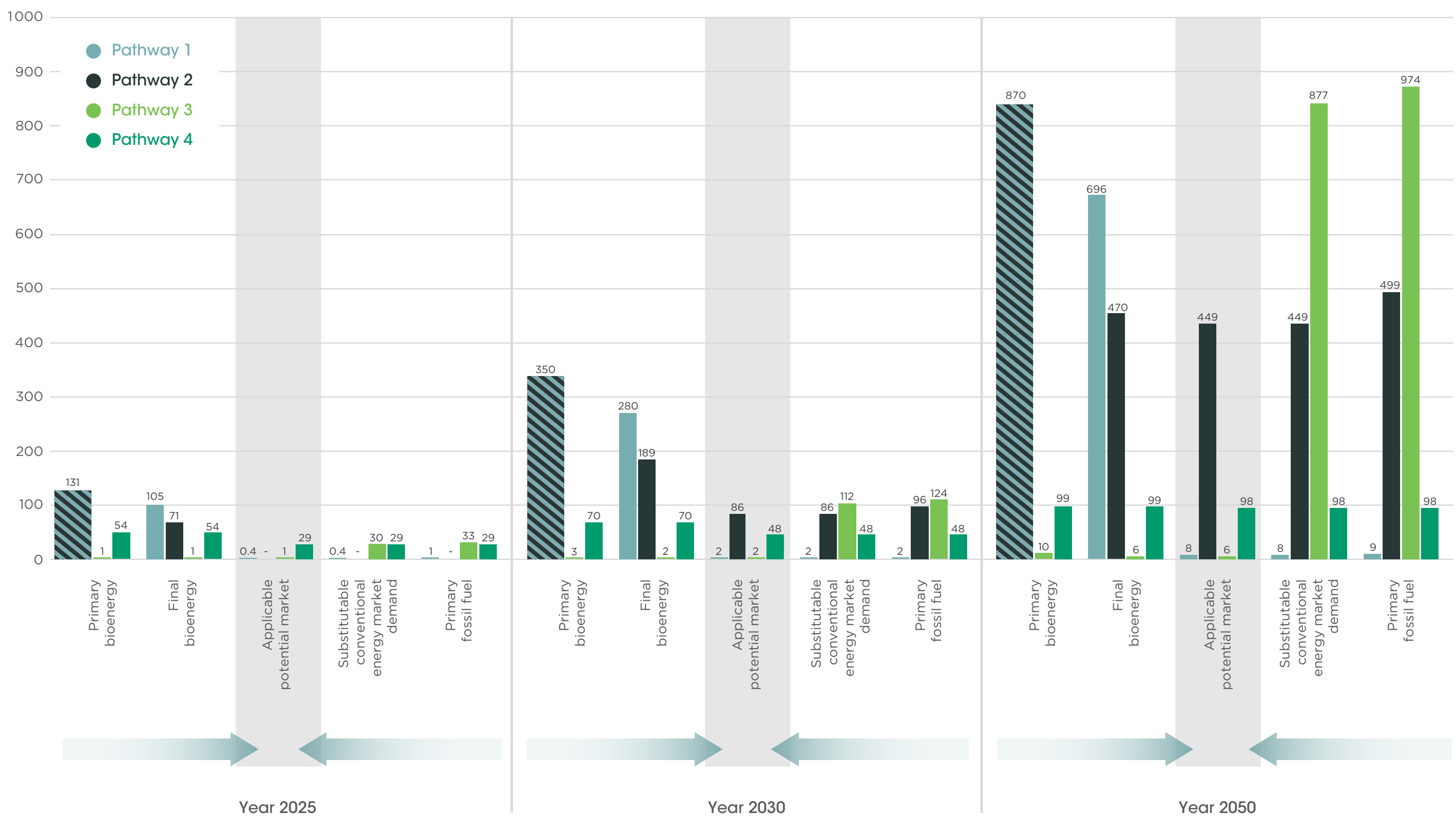
TABLE 19: Feedstock and process identified for each bioenergy pathway, Thailand

Type of Feedstock	Type of Process
Agricultural residues from major crops, rubber and teak	Direct combustion for industrial heat generation
	Direct combustion for combined heat and power generation
Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants
Sugarcane molasses and cassava roots and starch to bioethanol	Fermentation & blending to produce bioethanol

Substitutable markets for biomass have been estimated over three different horizons, namely 2025 (short term), 2030 (medium term) and 2050 (long term).

Based on the bioenergy supply and demand estimated in this study, prospective bioenergy pathways have been mapped through several of the most probable applications of biomass as a fuel source in Thailand's energy mix:

FIGURE 22: Bioenergy pathways in Thailand (2025, 2030 and 2050) in PJ



The total applicable potential market in Thailand is estimated to be around 30 PJ in 2025, 137 PJ in 2030, and 560 PJ in 2050.

BOX 6: SIAM CEMENT GROUP, BIOMASS TO ENERGY

Siam Cement Group is a Thai cement manufacturer that has shifted to renewable biomass instead of fossil fuels, substantially reducing their carbon emissions and providing socio-economic benefits for surrounding communities. New infrastructure now enables the five cement manufacturing plants involved in this project to use alternative fuels and biomass residues, including rice husks, wood processing residues and other agricultural waste. These are among the biomass processing feedstocks that can be applied in the industrial sector.

Bioenergy pathway 1 (direct combustion for industrial heat generation)

Pathway 1 focuses on the replacement of brown coal with biomass in heat boilers. Brown coal is mostly consumed in non-metallic minerals (e.g. cement), and the pulp and paper industry in Thailand; the total amount of brown coal consumed in the industry sector was over 7 PJ in 2017 (IEA, 2020).

However, biomass is not yet a proven ready substitute for certain applications such as steel smelting utilising coking coal or high-pressure steam-raising. Such sources of demand are selectively included in the long-term horizon assessments to 2050, where R&D has potential to develop alternative industrial processing to enable bioenergy to be used in such applications.

Retrofitting is considered a suitable approach by this study to create and facilitate the introduction of biomass as an economically viable substitute energy source in the short and medium terms. The substitutable market is evaluated at 0.4 PJ, 2 PJ and 8 PJ by 2025, 2030 and 2050, respectively.

Bioenergy pathway 2 (direct combustion for combined heat and power generation)

Pathway 2 focuses on replacing the remaining coal used in industry with biomass in CHP plants. Compared to brown coal, black coal provides better burning efficiency owing to its lower moisture content and higher carbon content. In Thailand, it is mostly used in industries such as food and tobacco production, and the production/processing of non-metallic minerals. The total consumption of black coal in these sub-sectors in Thailand is around 305 PJ (IEA, 2020). It is also used to produce electricity for industry (around 56 PJ). Biomass can replace such coal, which can then be used as feedstock for CHP plants that provide the highest overall conversion efficiency. Pathway 2 selects black coal used in a CHP plant as a market in which bioenergy have a significant impact as an energy source.

In the short term, this study assumes there will not be any CHP capacity built and completed by 2025. In the medium and long term, with new-build biomass CHP plants, this study assumes that 15% of black coal used in industry for producing heat and electricity will be replaced or equivalent amount in power sector by biomass-fuelled CHP plants in 2030, increasing to 75% in 2050. The substitutable market is evaluated at 86 PJ and 449 PJ by 2030 and 2050, respectively.

Bioenergy pathway 3 (anaerobic digestion to generate biogas for both heat boilers and CHP plants)

Cassava pulp is a by-product of the cassava starch industry that contains large amounts of carbohydrate, which is favourable for biogas production. Additionally, utilisation of cassava pulp diverts the biomass from disposal and converts the waste product into bioenergy. This pathway focuses on replacing natural gas with biogas in heat boilers in the short term and CHP plants in the medium and long terms.

For pathways 2 and 3, the demand for heat and power included in this analysis will be limited to large industrial facilities, such as large industrial parks for downstream manufacturing and processing where future heat demand is clustered and can be met by gas-fired steam boilers or gas-fuelled CHP plants, and the electricity supply is connected to power grids. Total natural gas consumption in the industry sector was approximately 469 PJ in 2017 (IEA, 2020).

In the short term, this study assumes that 5% of natural gas consumed in heat boilers can be replaced by biogas by 2025. In the medium and long terms, with new-built biogas CHP plants, this analysis assumes that 15% of natural gas used in industry for heat and electricity production will be replaced by biogas-fuelled CHP plants in 2030, increasing to 75% in 2050, while cassava pulp is also an option for grid-connected power generation.

The substitutable market is evaluated at 30 PJ, 112 PJ and 877 PJ by 2025, 2030 and 2050, respectively. The analysis conducted as part of this study identifies that, in the short and medium terms, biogas from cassava pulp can act as a substitutable energy source for natural gas. However, due to limiting factors such as accessibility and collectability, biogas generated from cassava pulp feedstock can only act as a substitutable energy source for 2% (6 PJ) of demand by 2050.

Bioenergy pathway 4 (fermentation and blend)

During the refinery process for sugar from sugarcane, molasses will be generated as a by-product, which can be used to produce ethanol. Thailand produced 3.5 million litres of ethanol a day in 2015. According to the Alternative Energy Development Plan 2015, Thailand aims to produce 9 million litres of ethanol per day by 2021. The government is positioning Thailand as a hub for ethanol trading in Southeast Asia.

This pathway depicts an applicable potential of 98 PJ in 2050. The production volume of ethanol in Thailand is ~4 billion litres. The Thai government has an ethanol consumption target under the latest AEDP of approximately ~2.6 billion litres in 2036, a decrease from the initial target of 4.1 billion litres stated in AEDPs pre-2015 (Prasertsri et al., 2020). The projected production volume will exceed both sets of target volumes envisaged by the Thai government under the bioethanol blending policies introduced in the early 2000s, implying that successful implementation of bioenergy pathway 4 will help Thailand reach its target production volumes. The assumptions in this study align with the blending ratio targets announced by the government. The substitutable market is evaluated at 29 PJ, 48 PJ and 98 PJ by 2025, 2030 and 2050, respectively.

Economic assessment

A summary of the findings from our bioenergy economic analysis for Thailand is presented in the following dashboard and summary table.

FIGURE 23: Summary dashboard for all bioenergy pathways in Thailand, 2050

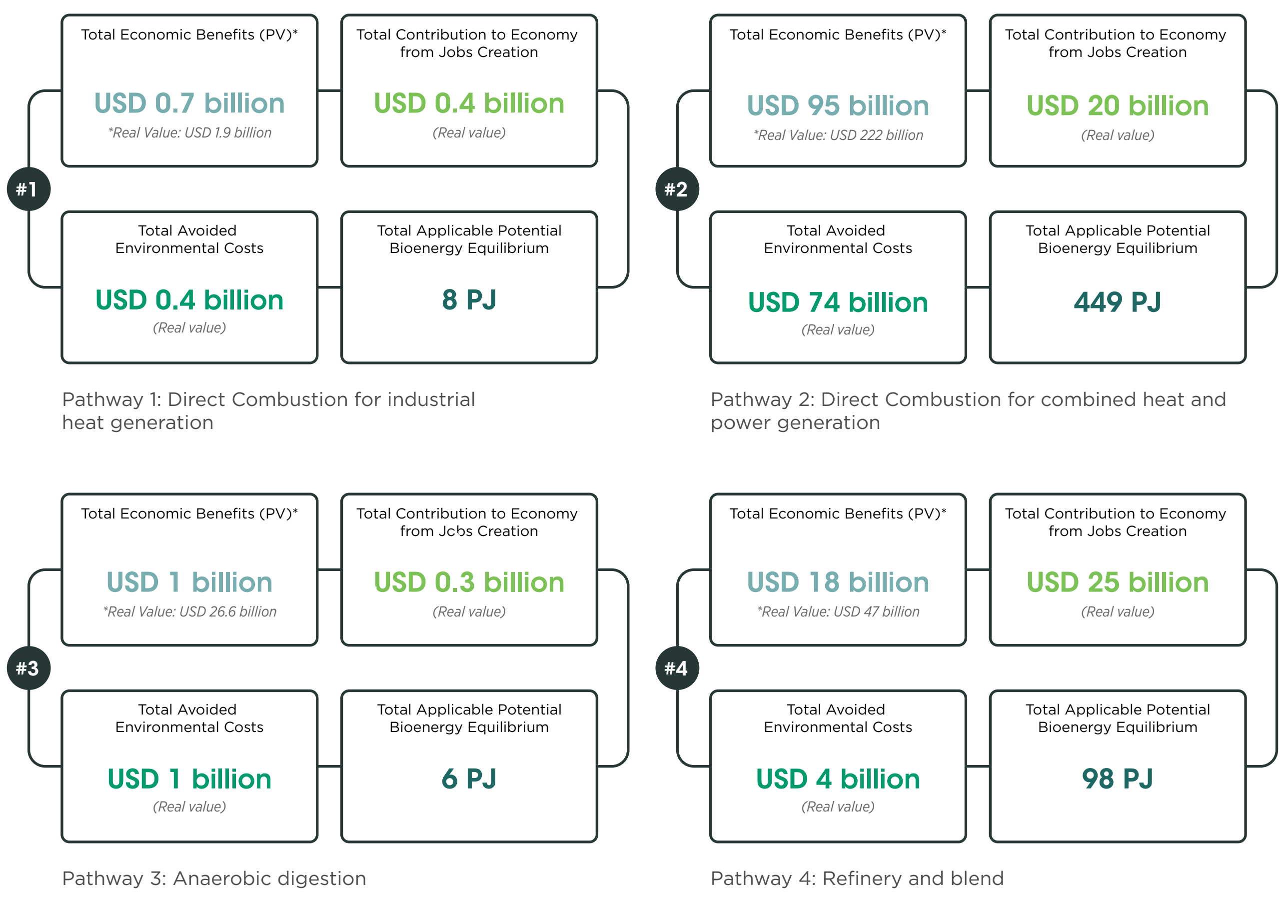


TABLE 20: Summary of findings for all bioenergy pathways, Thailand

Type of feedstock	Type of process	Total applicable potential bioenergy equilibrium (2050)	BCR (2050)	Total net present value of economic benefits (NPV) in USD bn (2050)
Agricultural residues from major crops, rubber and teak	Direct combustion for industrial heat generation	8 PJ	1.35	0.2
	Direct combustion for combined heat and power generation	449 PJ	1.19	15
Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants	6 PJ	1.32	0.3
Sugarcane molasses and cassava roots and starch to bioethanol	Fermentation & blending to produce bioethanol	98 PJ	2.26	9.9

These four bioenergy pathways result in a BCR above 1 and result in significant impacts on the economy of Thailand, amounting to approximately USD 26 billion of net present value of socio-economic benefits in 2050, creating over 116 000 new resilient jobs and saving over 102 million tonnes of GHG emissions per year. The real values (in USD million) of socio-economic costs and benefits are estimated for the years 2025, 2030 and 2050, and adjusted for economic inflation. The results for each bioenergy pathway are shown below.

FIGURE 24: Total cost and breakdown of benefits in USD million (real value), Thailand – pathway 1

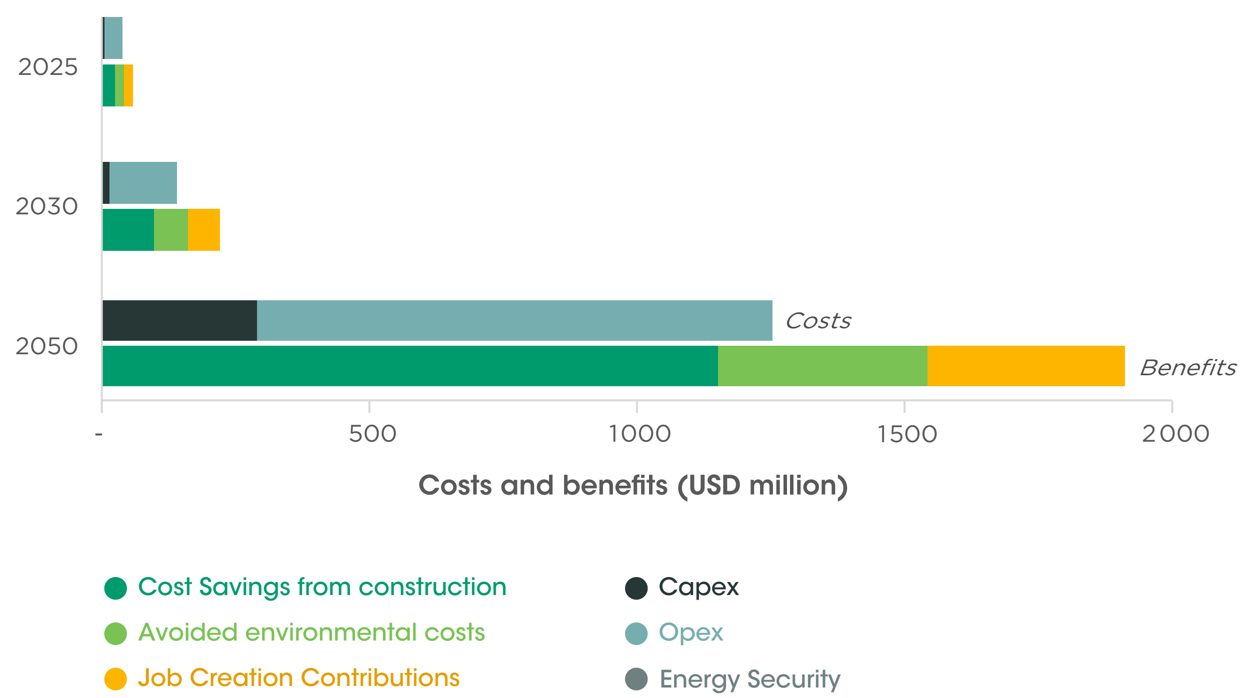


FIGURE 25: Total cost and breakdown of benefits in USD million (real value), Thailand – pathway 2

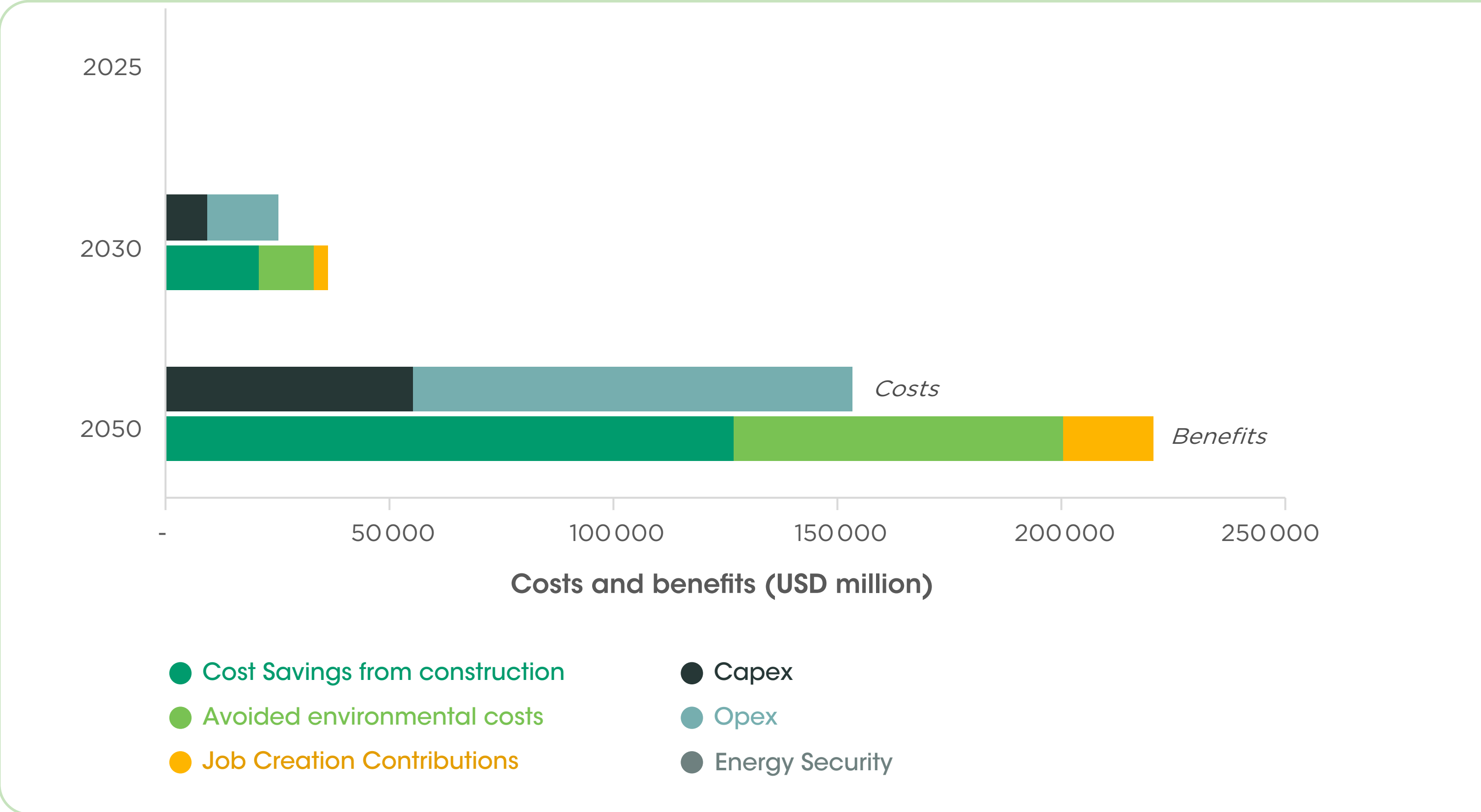


FIGURE 26: Total cost and breakdown of benefits in USD million (real value), Thailand – pathway 3

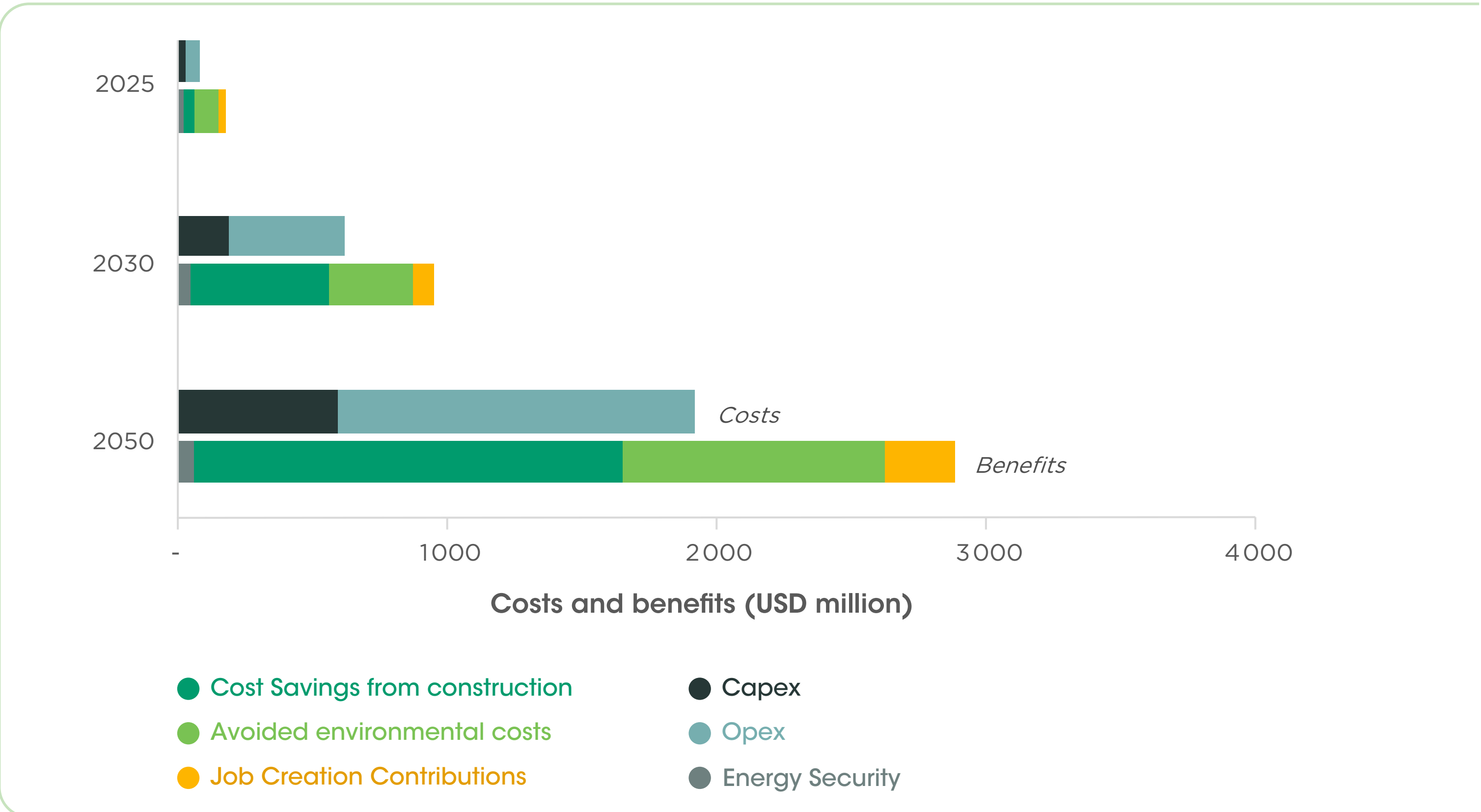
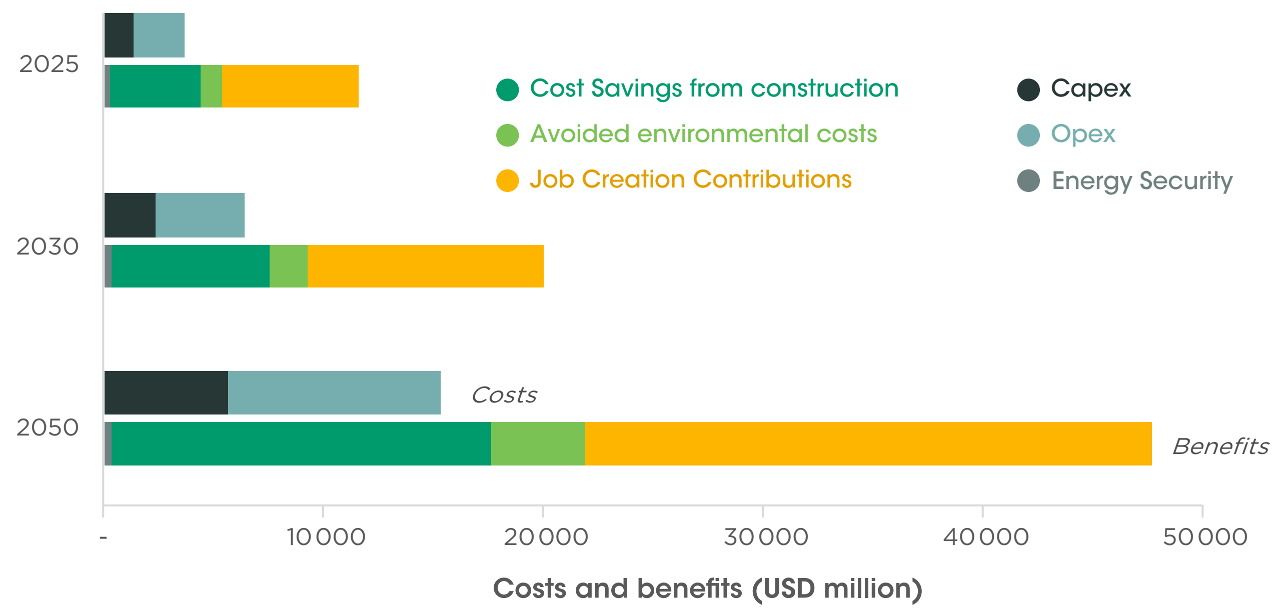


FIGURE 27: Total cost and breakdown of benefits in USD million (real value), Thailand – pathway 4



The bulk of socio-economic benefits to be derived from the pathways stem from:

- cost savings from construction;
- avoided environmental costs;
- benefits from resilient employment; and
- improvement of energy security.

Socio-economic benefits

I. COST SAVINGS FROM CONSTRUCTION

The figures below summarise cost savings from construction realised through the implementation of the four bioenergy pathways, based on an evaluation of GWe avoided from the costs of construction and operation of a traditional fossil fuel plant. The cost of constructing biofuel plants is included in this study's cost analysis.

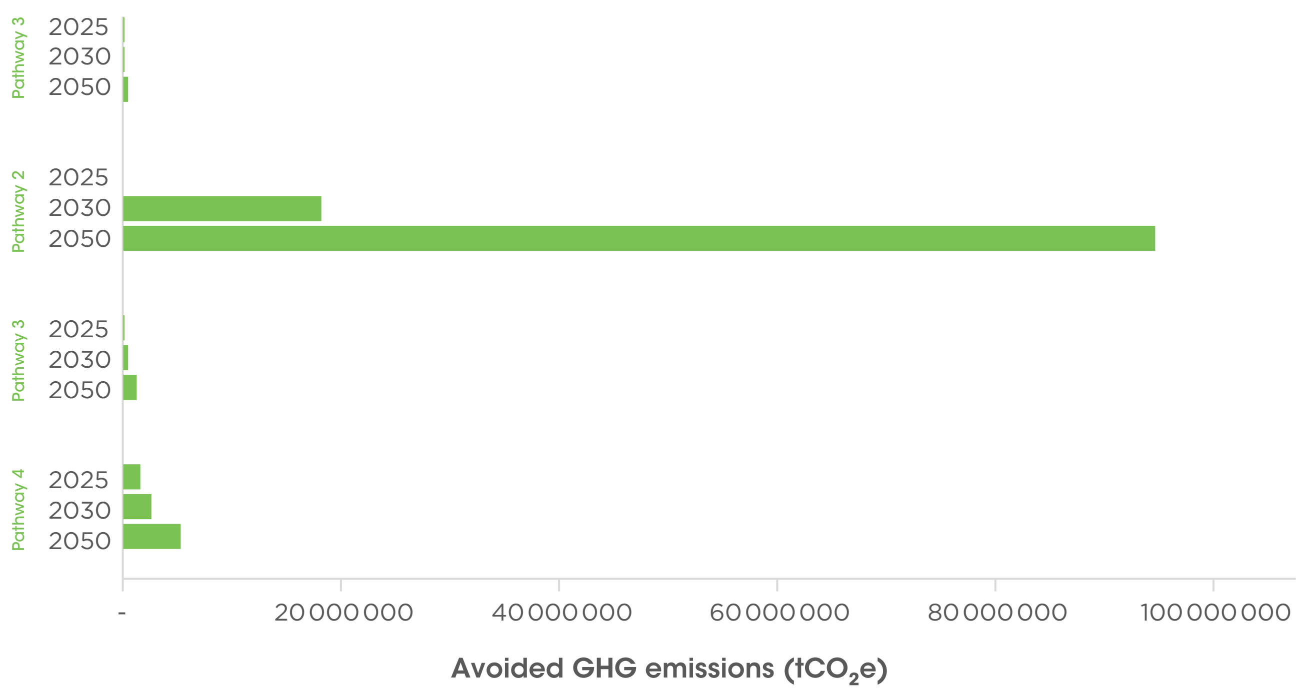
TABLE 21: Capacity of traditional fossil fuel plant saved (GWe), Thailand

Capacity of traditional fossil fuel plant saved	2025	2030	2050
Capacity of industrial heating facilities saved (GWe)	0.02	0.1	0.3
Capacity of CHP/power plants saved (GWe)	0.03	3.5	18.0
Capacity of gasoline plants saved (million litres per day)	3.4	5.6	11.5

II. AVOIDED GHG EMISSIONS SAVINGS COST

Further socio-economic benefits can be depicted through avoided GHG emission savings, comparing biomass energy plants with traditional fossil fuel energy plants.

FIGURE 28: Estimated GHG emissions avoided in Thailand (tCO_2e)



This represents GHG emissions savings of approximately 0.5 million tCO_2e, 95 million tCO_2e, 1.2 million tCO_2e and 5.3 million tCO_2e for pathways 1, 2, 3 and 4 by 2050, respectively.

Thailand has recognised its rising GHG emissions since 2000 stemming from the need to meet increasing demand and economic growth (Ritchie and Roser, 2018). Although these bioenergy pathways alone would not be enough for Thailand to stem rising GHG emissions and meet their 2015 Paris Climate Agreement targets, the GHG emissions savings realised will help Thailand to reach its commitments.

III. BENEFITS FROM RESILIENT EMPLOYMENT (NET JOB BENEFITS[20])

By 2050, approximately 116 000 resilient jobs in Thailand will be created by implementing these bioenergy pathways.

20 Benefits are calculated as net job benefits, meaning the figure accounts for lost jobs in coal, oil and gas industries.

The figures below provide an overview of the resilient jobs created through the implementation of bioenergy pathways in terms of number of jobs in the farming and non-farming categories.

FIGURE 29: Estimated number of resilient jobs created in Thailand – bioenergy pathway 1

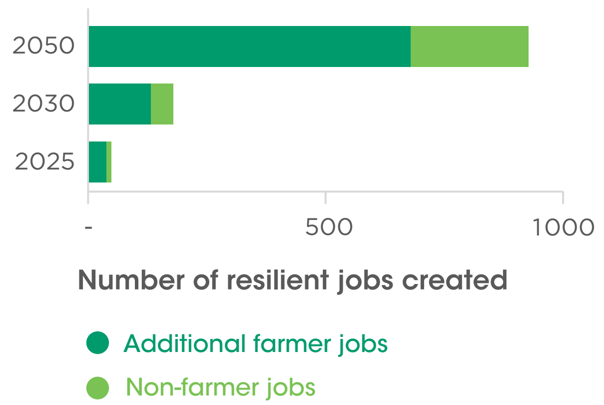


FIGURE 30: Estimated number of resilient jobs created in Thailand – bioenergy pathway 2

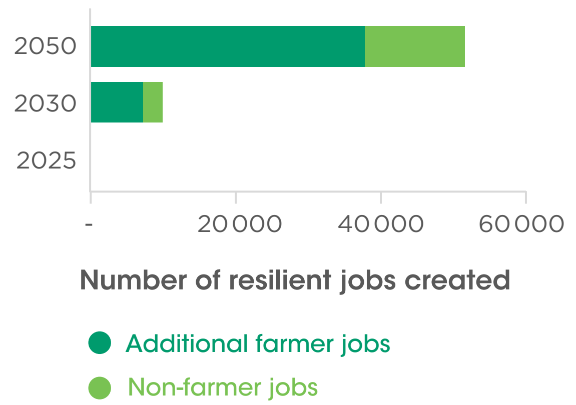


FIGURE 31: Estimated number of resilient jobs created in Thailand – bioenergy pathway 3

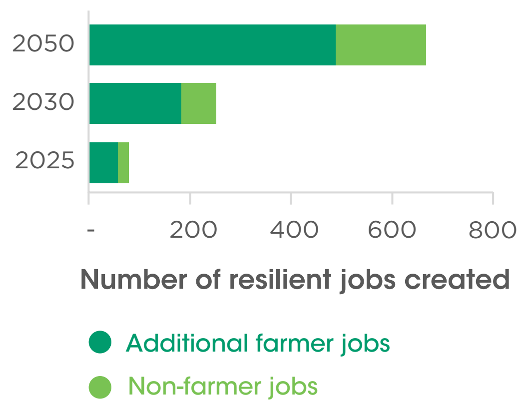
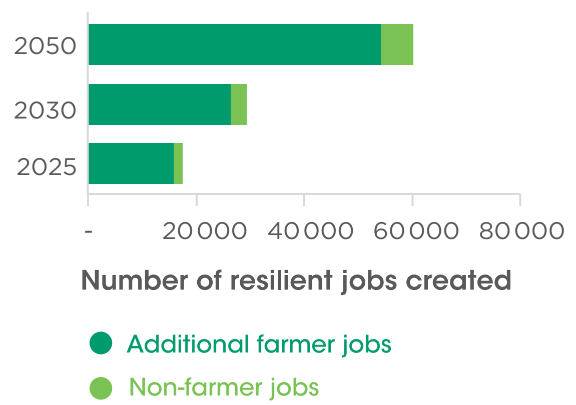


FIGURE 32: Estimated number of resilient jobs created in Thailand – bioenergy pathway 4



IV. IMPROVEMENTS IN ENERGY SECURITY

The figures below summarise potential improvements in energy security realised through implementation of the four bioenergy pathways. The analysis considers the decrease in reliance on fossil fuel imports (i.e. cost of buying traditional fuels from overseas) and GDP impact of rising fuel prices.

TABLE 22: Percentage of fossil fuel imports saved, Thailand

Percentage of fossil fuel imports saved	2025	2030	2050
Percentage of coal imports saved	0.1%	8%	19%
Percentage of natural gas imports saved	0.1%	0.2%	0.3%
Percentage of oil imports saved	1%	2%	2%

The table indicates an increasing improvement in energy security over the short-, medium- and long-term horizons, as the increased production of biofuel through all pathways correlates with a direct reduction in reliance on traditional fossil fuel imports. By 2050, Thailand would achieve USD 659 million in energy security improvements if all pathways are successfully implemented. In addition to the benefits quantified, implementing bioenergy projects will also help countries mitigate the risk of energy supply shortages due to a reduction in, or halting of, fossil fuel supplies from other countries and their costs.

Summary of findings

The average annual cost required to realise the four bioenergy pathways is estimated to be around USD 3 billion through 2050. In this study, costs include capital expenditure, operations and maintenance costs. On the other hand, average annual socio-economic benefits achieved through the implementation of the pathways would exceed average annual economic costs by USD 0.9 billion through 2050, resulting in net positive gains.

Utilising the analysis conducted above, the consequent total socio-economic benefits derived from each bioenergy pathway are presented in ENPV and calculated as a BCR:

TABLE 23: Socio-economic outcomes arising for potential bioenergy pathways in 2050, Thailand

Bioenergy pathways	Present value of total economic costs for each bioenergy pathway (in USD million)			Economic net present value of total socio-economic benefits for each bioenergy pathway (in USD million)			Benefit-cost ratio for each bioenergy pathway		
	2025	2030	2050	2025	2030	2050	2025	2030	2050
Bioenergy pathway 1 direct combustion for industrial heat generation	13	49	533	4	15	188	1.31	1.31	1.35
Bioenergy pathway 2 direct combustion for combined heat and power generation	-	13 069	79 725	-	2 525	15 265	-	1.19	1.19

Bioenergy pathway 3 anaerobic digestion to generate biogas for both heat boilers and CHP plants	36	298	928	17	105	298	1.47	1.35	1.32
Bioenergy pathway 4 fermentation to produce bioethanol and blending	1 879	3 260	7 830	2 435	4 190	9 877	2.30	2.29	2.26
Total	**1 928**	**16 676**	**89 016**	**2 456**	**6 836**	**25 628**			

Key observations from this assessment are:

- BCR values for all bioenergy pathways are greater than 1.0, thus all bioenergy pathways would deliver strong ENPV of socio-economic benefits to Thailand, amounting to over USD 26 bn of net benefits in 2050.
- bioenergy pathway 2 offers the most significant potential socio-economic impact (ENPV of ~USD 15 bn in 2050). This result suggests that Thailand can consider coal phase-out in an economically viable manner, taking advantage of the benefits derived from this pathway.

Key barriers and interventions

This study reviewed Thailand's current bioenergy framework using political, economic, social, environmental, technological, legal and financial (PESTEL&F) parameters parameters to identify key barriers to implementing the bioenergy pathways identified above, and the various interventions required.

Key barrier 1: Lack of R&D initiatives to sustainably improve the yield of Thai agricultural products

A lack of R&D initiatives as a whole was identified when Thailand's bioenergy market was analysed through the technological parameter. Increasing the number of R&D initiatives will positively contribute to the advancement of bioenergy-related technology and methodologies within the region.

An improvement in agricultural yields is a key assumption that this study makes in facilitating sustainable bioenergy production, where an increase in yield directly correlates to a decrease in the need to expand arable land to meet growing agricultural production demands.

Sugarcane is one of Thailand's key agricultural products and is a key biomass feedstock source (sugarcane molasses) analysed as part of this study. The planted area for sugarcane in Thailand has been stable at 1 million ha since 2008, but crop yield has not increased significantly and is susceptible to climate change and disease (ADB, 2009). To raise the bioenergy potential from sugarcane cultivation, the widespread adoption of energy cane varieties with much higher yields than conventional sugarcane can be promoted through R&D.

- For each biofuel pathway to succeed, whilst limiting sustainable and environmental concerns when production is scaled, there needs to be a yield improvement for Thailand's agricultural crops and, subsequently, agricultural residues.
- The government can incentivise investments in R&D to help Thai farmers improve their farming techniques/processes/tools and can introduce programmes to facilitate this journey.

Key barrier 2: Public perceptions of bioenergy

The socio-economic benefits of bioenergy consumption are not common knowledge in Thailand. This barrier was identified by examining Thailand's bioenergy market through the social parameter of the PESTEL&F analysis.

The Thai government developed the first National Alternative Energy Development plan with particular focus on the production mandate for biofuels, as well as non-tax and tax incentives, research and public awareness promotion (Wattana, 2014). Increasing positive public perceptions of bioenergy as a sustainable source of energy, whilst providing information regarding how negative impacts are mitigated, could see a public transition to bioenergy as a primary energy source even if prices are higher than traditional fossil fuels. The Thai government can seek to change this perception through running marketing campaigns and other programmes to increase the public's awareness of bioenergy.

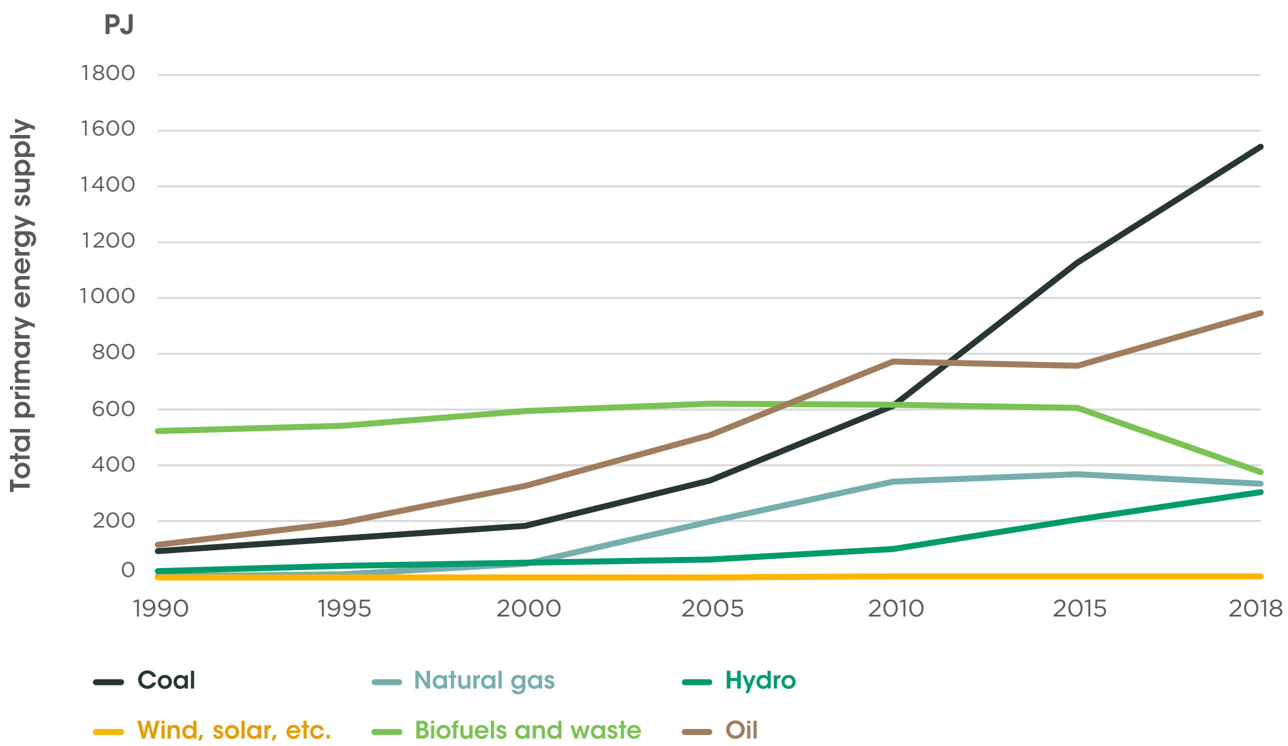
c. Vietnam

Vietnam can unlock significant socio-economic benefit potential by utilising the biomass feedstock it produces from its large agricultural industry.

Vietnam has a land area of 31 million ha, comprising 12 million ha of arable land and 14 million ha of forest (FAO, 2020c). Agriculture is one of the most important economic sectors in Vietnam, contributing 14% of the country's GDP (WBG, 2021).

As presented in Figure 33, bioenergy is the largest energy source among renewables in Vietnam, with a primary supply amounting to 342 PJ in 2018. Currently, biomass is generally treated as a non-commercial energy source and used locally (Zafar, 2019), whilst the latest energy data note that the majority of bioenergy consumption in Vietnam occurs in the industry sector (IEA, 2019). To improve access to electricity, a Dutch-funded biogas program oversaw the installation of biogas digesters in rural and semi-urban settings to provide these communities with power, which could lead to steady demand for biomass feedstock in the future. The supply of bioenergy has been consistent for the past few decades, barring a notable decrease in supply in 2018.

FIGURE 33: Total primary energy supply in Vietnam, 1990–2018



Source: IEA (2020)

Potential bioenergy pathways for Vietnam are presented below, having been identified through the four push and pull factors outlined in Section 2.

Bioenergy pathways

Identifying available biomass feedstocks in Vietnam

I. AGRICULTURAL RESIDUES FROM MAJOR CROPS, RUBBER AND EUCALYPTUS

Vietnam is a major global producer of coffee and pepper, rice and cashew nuts, coconut, cassava, and sweet potatoes (FAOSTAT, 2021). The three agricultural crops with the largest potential to scale up residue-derived bioenergy are rice, sugarcane and maize, including via rice straw, rice husks, sugarcane bagasse, tops and leaves, maize cob, husks and straws.

Vietnam has a thriving forest sector, producing over 36 million m^3 of industrial roundwood for sawn timber, plywood, pulp and other fibre materials, while another 20 million m^3 of wood fuel was produced mainly for traditional cooking in 2019 (FAOSTAT, 2021). The development of eucalyptus plantations in Vietnam has made the country one of the world's largest producers of wood chips for the pulp industry (pulpwood accounts for c. 20 million m^3 of industrial roundwood production). Additionally, Vietnam is the third largest producer of natural rubber in the world. As is the case for Indonesia and Thailand, rubberwood has considerable potential as a bioenergy feedstock.

Through wood value chains, large volumes of residues and waste are generated in various forms such as treetops, branches, low-grade trees, bark, sawdust and unnecessary portions of roundwood after being processed into sawn lumber. These residues can be used as feedstock for bioenergy; however, this study focuses on woody biomass that can be sourced from plantation forests, as more in-depth analysis would be needed to assess whether wood extracted from natural forests can be considered a sustainable feedstock.

II. CASSAVA PULP

Cassava is one of the most important crops in Vietnam, along with rice and corn, both in terms of harvested area and total production. Cassava is grown across the country, with one crop season per year in the north and three crop seasons every two years in the south (Pirelli, Rossi and Miller, 2018). Large cassava production across the entire country leads to large volumes of by-products as cassava is processed for end-use.

Cassava pulp is a solid waste by-product of the starch production process. Cassava pulp has a high starch content (50%–60% dry basis), causing an environmental problem with disposal (Sriroth et al., 2000). Cassava pulp contains large amounts of carbohydrate, which is favourable for biogas production.

III. SUGARCANE MOLASSES

Although Vietnam is not a global leader in terms of sugarcane production and exports, the sugarcane industry in Vietnam is still sizeable, with 18 million tonnes of sugarcane produced in 2018 (FAOSTAT, 2021). There are 36 sugar mills and one refinery operating in Vietnam, with a total installed capacity of 62 300 tonnes cane/day (Duong, 2020).

As of 2018, domestic bioethanol is being produced from sugarcane molasses but at a small scale. Vietnam only has one factory using molasses in combination with cassava for ethanol production. Approximately 100 million tonnes of ethanol are produced annually, of which bioethanol produced from sugarcane molasses makes up a very small percentage (Trinh and Linh Le, 2018), indicating good potential for further developments.

TABLE 24: Vietnam's potential biomass energy sources – selected, available bioenergy feedstock

Type of feedstock	Quantity available (million tonnes)		
	2025	2030	2050
Rice husks, rice straw	25.7	27.1	28.8
Sugarcane bagasse, tops and leaves	4.9	5.1	5.4
Maize cob/Husk/stover/straw	2.9	3.1	3.3
Rubber	1.8	1.9	2.0
Eucalyptus	1.0	1.0	1.1
Cassava pulp	4.3	4.6	4.8
Sugarcane molasses	0.8 (Ethanol: 0.21 billion litres)	0.85 (Ethanol: 0.22 billion litres)	0.9 (Ethanol: 0.23 billion litres)
Total	**41.3**	**43.7**	**46.4**

Source: IRENA (2017a)[21]

This study assumes that year-on-year increases in the quantity of these feedstocks available will be achieved at a rate of 1.1% from 2025 to 2030 and 0.3% from 2030 to 2050, stemming from an assumed increase in yield per unit of land. Yield increase can be made possible by adopting new farming technologies such as mechanisation, cultivar improvement, precision agriculture as well as digital applications for monitoring and

21 The quantity available for woody biomass provided in IRENA report – Biofuel Potential in Southeast Asia is estimated based on annual woody biomass increment multiplied by energy wood share. The energy share of total woody biomass is 20% for pulp wood and 40% for lumber and furniture wood. The quantity available for harvest residues is limited to 25% of total harvest residues to ensure the soil quality and biodiversity.

weather forecasting. Throughout this period, no land use change would occur, with a view to halting deforestation, and residue-to-crop production ratios remain constant.

It is worth noting that demand for conventional uses of the residues for animal feed and bedding, rubber for timber, and furniture and eucalyptus for pulp and paper are all deducted from the total quantity available.

Identifying collectible biomass feedstocks in Vietnam

As is the case also in Indonesia and Thailand, the collection of bioenergy feedstocks faces several logistical challenges owing to their decentralised location, which acts as a barrier that results in some residues being left uncollected and untreated.

As biomass feedstock becomes gradually available over time, the collectible quantity also increases. This study assumes the collection ratio for applicable feedstock[22] to increase from 10% in 2025 to 30% in 2030 and further to 75% in 2050 for agricultural residue; and 30%, 50%, and 90% in 2025, 2030 and 2050, respectively, for woody biomass. Finally, this study assumes the feedstock collection ratio to increase from 30% in 2025 to 50% in 2030 and 80% in 2050 for sugarcane molasses (see the table below).

TABLE 25: Vietnam's potential biomass energy sources – selected, collectible bioenergy feedstock [23]

Type of feedstock	Quantity collected for bioenergy feedstocks (million tonnes)		
	2025	2030	2050
Rice husks, rice straw	2.6	8.1	21.6
Sugarcane bagasse, tops and leaves	0.5	1.5	4.1
Maize cob/husk/stover/straw	0.3	0.9	2.5
Rubber	0.5	1.0	1.8
Eucalyptus	0.3	0.5	1.0
Cassava pulp	0.4	1.4	3.6
Sugarcane molasses	0.24 (Ethanol: 0.06 billion litres)	0.42 (Ethanol: 0.11 billion litres)	0.72 (Ethanol: 0.19 billion litres)
Total	**4.9**	**13.9**	**35.3**

22 The applicable feedstock excludes conventional use of the residues for animal feed and bedding, rubber for timber and furniture and eucalyptus for pulp and paper.

23 Due to lack of available data on how many tonnes of each biomass feedstock type is already used as an energy source, this study assumes that all biomass feedstock analysed in this report are not utilised today and that the collection ratio of agricultural residues and woody biomass will increase over time.

The increasing quantity of biomass feedstock available over each of the horizons studied directly correlates to an increasing amount of biomass feedstock collectible. Other factors that contribute to this increase include:

- improvements in logistics management;
- improvements in stock-pile management; and
- improvements in surrounding infrastructure.

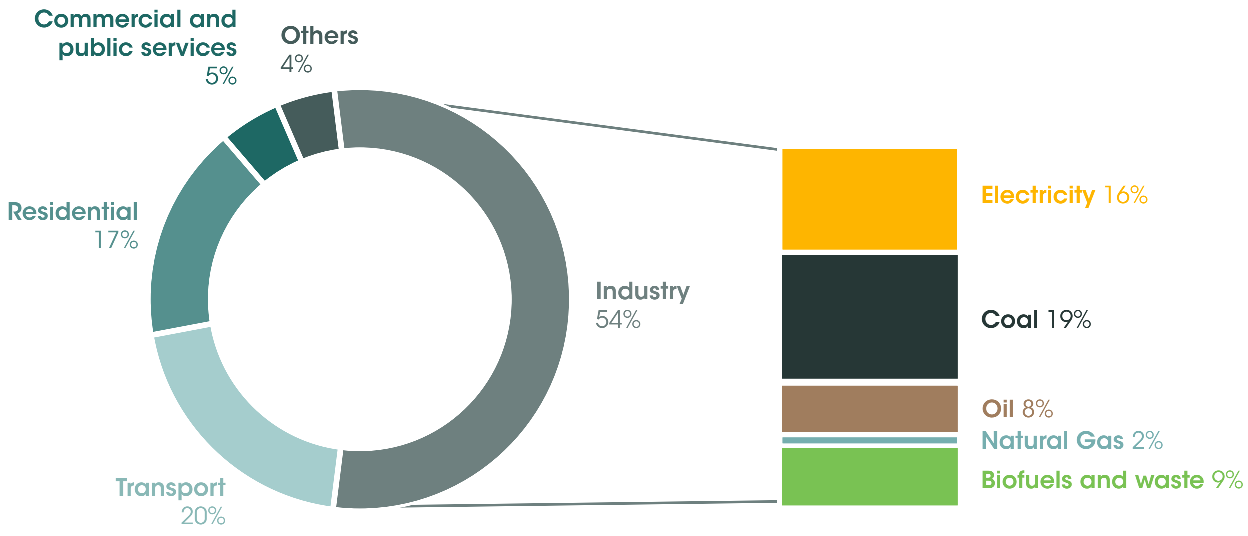
The biomass feedstock collectible is converted to PJ in the table below and presented as estimated potential primary bioenergy supply Vietnam would have available for each identified biomass feedstock. Corresponding bioenergy pathways are also presented.

TABLE 26: Vietnam's potential primary bioenergy supply – selected, collectible bioenergy feedstock

Type of feedstock	Primary bioenergy supply (PJ)		
	2025	2030	2050
Rice husks, rice straw	38.5	122.0	323.8
Sugarcane bagasse, tops and leaves	7.3	23.1	61.2
Maize cob/husk/stover/straw	4.4	13.9	36.8
Rubber	10.3	18.2	34.7
Eucalyptus	5.6	9.8	18.8
Cassava pulp	0.6	1.9	5.9
Sugarcane molasses	1.5	2.6	4.3
Total	**68.1**	**191.3**	**485.5**

Vietnam's energy mix

FIGURE 34: Vietnam's energy mix and usage of conventional fossil fuels in 2017



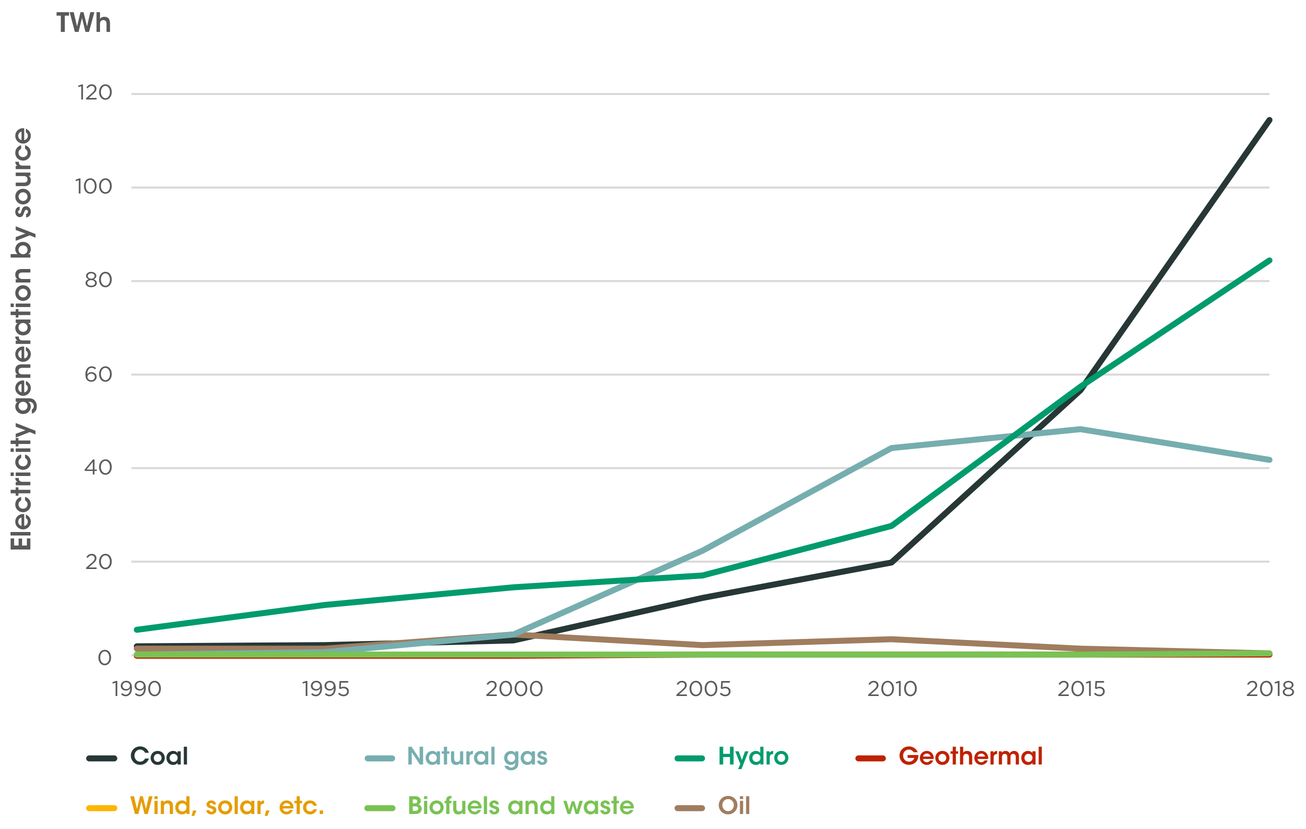
Source: IEA (2020)

The most probable applications for bioenergy in Vietnam are within the industry and transport sectors as substitutes for conventional fossil fuels. These sectors consume approximately 74% of Vietnam's energy (see Figure 34) and provide concentrated nodes of energy demand where fuel substitutions should be facilitated in a move toward a low carbon economy.

Figure 35 presents sources of electricity generation from 1990 to 2019. In 2019, biofuels contributed approximately 0.2 TWh, representing a negligible percentage of the country's electricity generation. Coal dominates the electricity generation mix at 115 TWh, with hydro and natural gas providing 84 TWh and 42 TWh, respectively.

Vietnam introduced the E5 (a mixture of 5% ethanol and 95% conventional gasoline) and B5 (a mixture of 5% biodiesel and 95% conventional diesel) blending mandates to incentivise increased consumption and production of local biofuels. In assessing the market outlook for biofuels, it is assumed that, if Vietnam decides to produce biofuel through E5 and B5 blending mandates, the country may be ready to produce biofuel to meet 10% of local petroleum demand in 2030 and 20% by 2050 (ADB, 2009).

FIGURE 35: Sources of electricity generation in Vietnam, 1990–2019



Source: IEA (2020)

Bioenergy pathways and substitutable markets identified in Vietnam

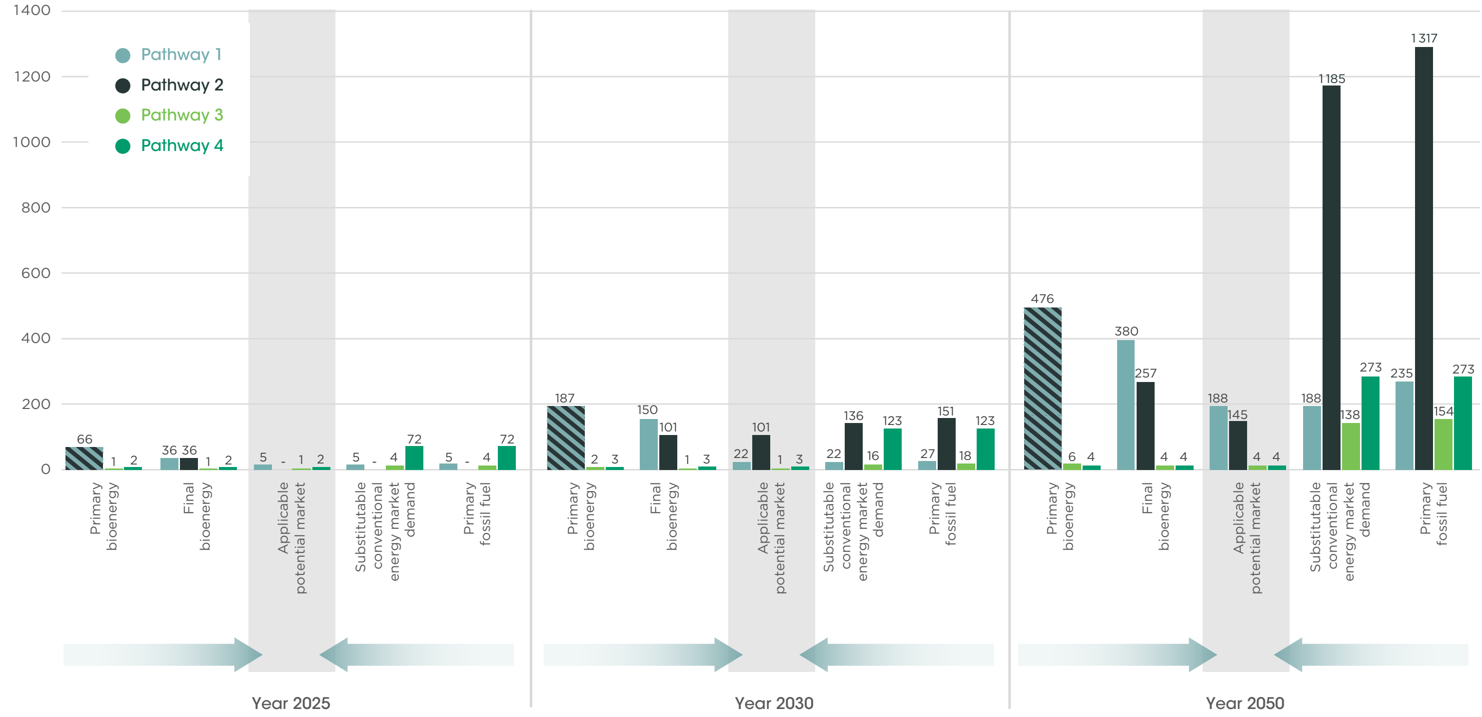
TABLE 27: Feedstock and processes identified for each bioenergy pathway, Vietnam

Type of Feedstock	Type of Process
Agricultural residues from major crops, rubber and eucalyptus	Direct combustion for industrial heat generation
	Direct combustion for combined heat and power generation
Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants
Sugarcane molasses to bioethanol	Fermentation & blending to produce bioethanol

Substitutable markets in Vietnam

The total applicable potential market in Vietnam is estimated at around 6 PJ in 2025, 127 PJ in 2030, and 340 PJ in 2050.

Figure 36: Bioenergy pathways in Vietnam (2025, 2030 and 2050) in PJ



Bioenergy pathway 1 (direct combustion for industrial heat generation) primarily focuses on brown coal used in heat boilers, but it is not a heavily consumed energy source in Vietnam. With current technology, the introduction of biomass feedstock into Vietnam's industrial sector can offset the need to consume brown coal in industries such as paper, textiles and sugar.

This pathway also includes the blending of coal with charcoal or bio-coke for iron and steel, and non-ferrous metals production (c. 19 PJ in 2017). However, as it is not yet a common approach in the country, it is only included in the mid- and long-term horizon assessments.

This study assumes that biomass can be used for co-firing with brown coal to produce heat in the short term and that 5% of brown coal can be replaced by 2025 with biomass in retrofitted co-firing boilers during the initial pilot phase. The substitutable market is evaluated at 5 PJ, 22 PJ and 188 PJ by 2025, 2030 and 2050, respectively.

Bioenergy pathway 2 (direct combustion for combined heat and power generation) focuses on replacing black coal used in industry for heat and electricity production with biomass in CHP plants. Compared to brown coal, the black coal provides better burning efficiency with its lower moisture level and higher carbon content and it is widely used in Vietnam's industries such as in production of non-metallic minerals, textiles and leather, and food and tobacco production. The total consumption of black coal in these sectors and in industry electricity production in Vietnam is around 453 PJ (IEA, 2020). Biomass can replace black coal as a feedstock in CHP plants, providing the highest overall conversion efficiency. Figure 35 depicts exponentially increasing electricity generated through coal as electricity demand increases across the country. The chart depicts negligible utilisation of bioenergy for electricity generation. Replacing the combustion of coal to produce electricity with biomass in a CHP plant will aid Vietnam in meeting rising electricity demand while mitigating environmental costs.

In the short term, this study assumes there will not be any combined heat and power to be built and completed by 2025. In the medium and long term, with the new-built biomass CHP plants, this analysis assumes that 15% of black coal fired heat boilers or equivalent amount of coal in power sector will be replaced by biomass-fuelled CHP plants in 2030, increasing to 75% in 2050. The substitutable market is evaluated at 135 PJ and 1 185 PJ by 2030 and 2050, respectively.

Bioenergy pathway 3 (anaerobic digestion to generate biogas for both heat boilers and CHP plants) focuses on replacing natural gas with biogas in heat boilers in the short term and CHP plants in the medium and long terms. In 2017, 53 PJ of natural gas is used to produce heat and electricity in industry (IEA, 2020). For pathways 2 and 3, the demand for heat and power included in this analysis will be limited to only large industrial facilities, such as sugar industries or large industrial parks for downstream manufacturing and processing where the future heat demand is clustered and can be met by gas-fired steam boilers or gas-fuelled CHP plants, with the electricity supply connected to power grids.

In the short term, this study assumes that 5% of natural gas consumed in the heat boilers can be replaced by biogas by 2025. In the medium and long terms, with new-built biogas CHP plants, this analysis assumes that 15% of natural gas fired heat boilers will be replaced by biogas-fuelled CHP plants in 2030, increasing to 75% in 2050.

The substitutable market is evaluated at 4 PJ, 16 PJ and 138 PJ by 2025, 2030 and 2050, respectively. In the short and medium terms, biogas from cassava pulp can act as a substitutable energy source for natural gas. However, due to limiting factors such as accessibility and collectability, biogas generated from cassava pulp feedstock can only act as a substitutable energy source for 2% (3.5 PJ) of demand by 2050.

Bioenergy pathway 4 (fermentation and blending) depicts an applicable potential of 4.3 PJ in 2050, with an equivalent estimated ethanol production volume of 0.2 billion litres. As discussed above, Vietnam has introduced the E5 and B5 blending mandates to increase local production of biofuel. In 2017, the biofuel E5 RON 92 accounted for 9% of total petrol consumption (Biofuels International, 2018). In 2018, consumption of E5 RON 92 rose to 40%, with 1.78 million m^3 of biofuel consumed during the first half of 2018. This represents a noticeable improvement in bioethanol consumption but does not note that the sales of ethanol blended gasoline (E5) has been negatively impacted in the country due to persistent rumours that it harms vehicle engines (USDA, 2020). The Government of Vietnam took steps in 2019 to mitigate these rumours by reducing the most-favoured nation import tariff on ethanol to 15% (USDA, 2020).

The assumptions in this study are made to align with the blending ratio target announced by the government; The substitutable market is evaluated at 72 PJ, 123 PJ and 273 PJ by 2025, 2030 and 2050, respectively.

Economic assessment

A summary of the findings from our bioenergy economic analysis is presented in the following dashboard and summary table.

FIGURE 37: Summary dashboard for all bioenergy pathways in Vietnam, 2050

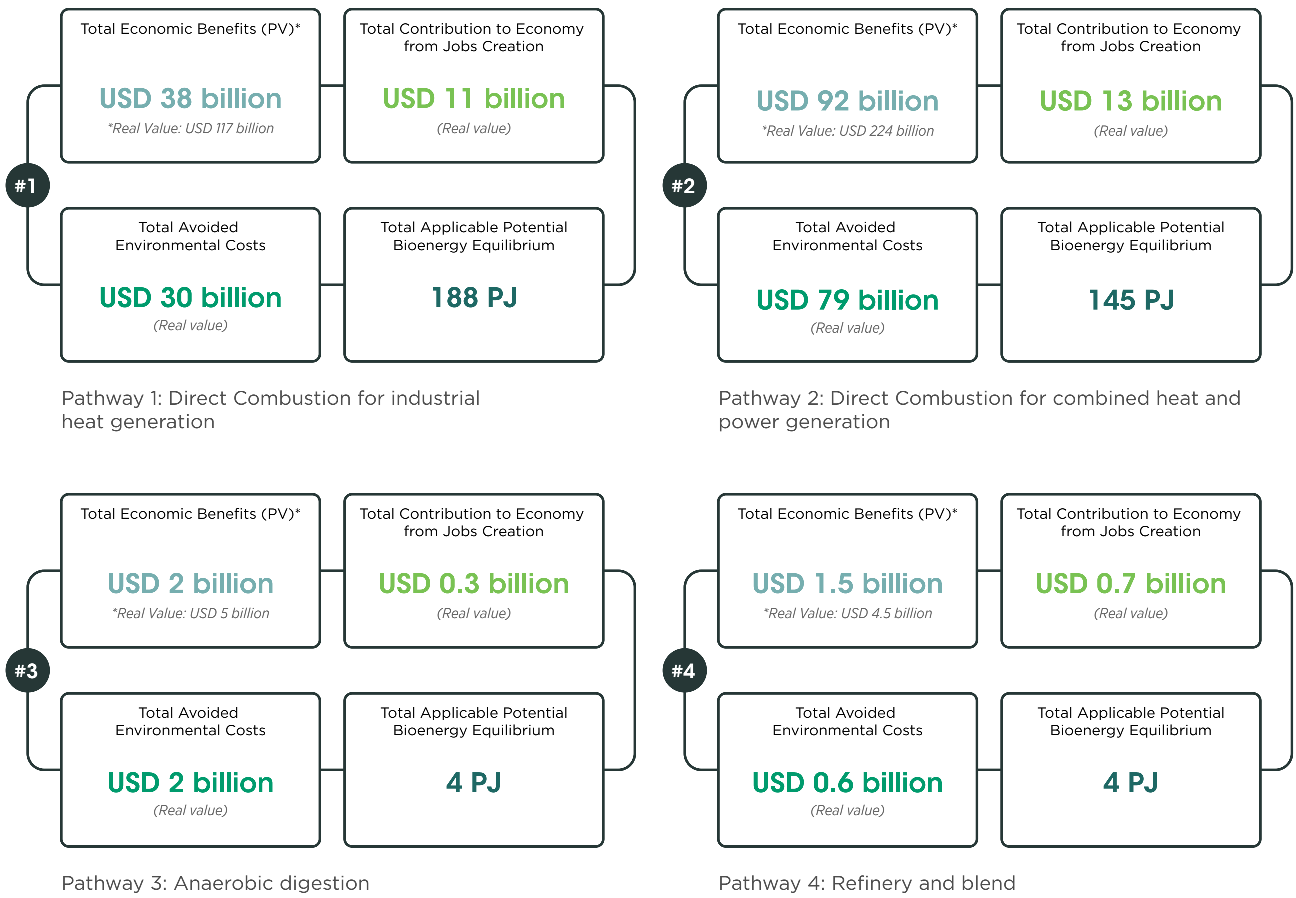


TABLE 28: Summary of findings for all bioenergy pathways, Vietnam

Type of feedstock	Type of process	Total applicable potential bioenergy equilibrium (2050)		BCR (2050)	Total net present value of economics benefits (NPV) in USD bn (2050)
Agricultural residues from major crops, rubber and eucalyptus	Direct combustion for industrial heat generation	188	PJ	1.27	7.8
	Direct combustion for combined heat and power generation	145	PJ	1.12	9.7
Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants	4	PJ	1.21	0.3
Sugarcane molasses to bioethanol	Fermentation & blending to produce bioethanol	4	PJ	1.92	0.7

These four bioenergy pathways result in BCRs above 1 and result in significant impacts on the economy of Vietnam, amounting to approximately USD 18.5 billion of net present value of socio-economic benefits in 2050, creating over 50 800 new resilient jobs and saving around 43 million tonnes of GHG emissions per year.

Real values (USD million) for the years 2025, 2030 and 2050, adjusted for economic inflation are presented below for each bioenergy pathway.

FIGURE 38: Total cost and breakdown of benefits in USD million (real value), Vietnam – pathway 1

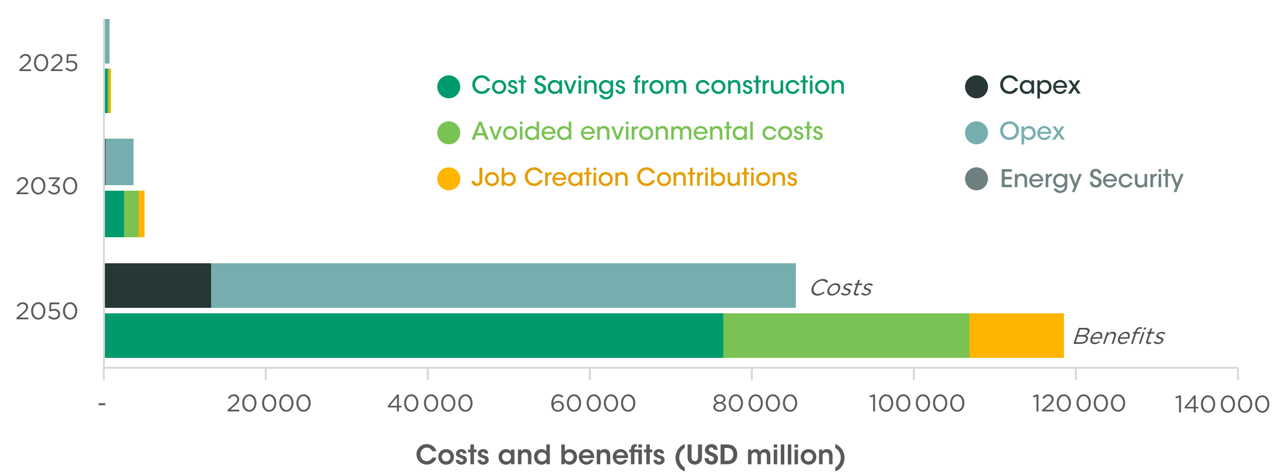


FIGURE 39: Total cost and breakdown of benefits in USD million (real value), Vietnam – pathway 2

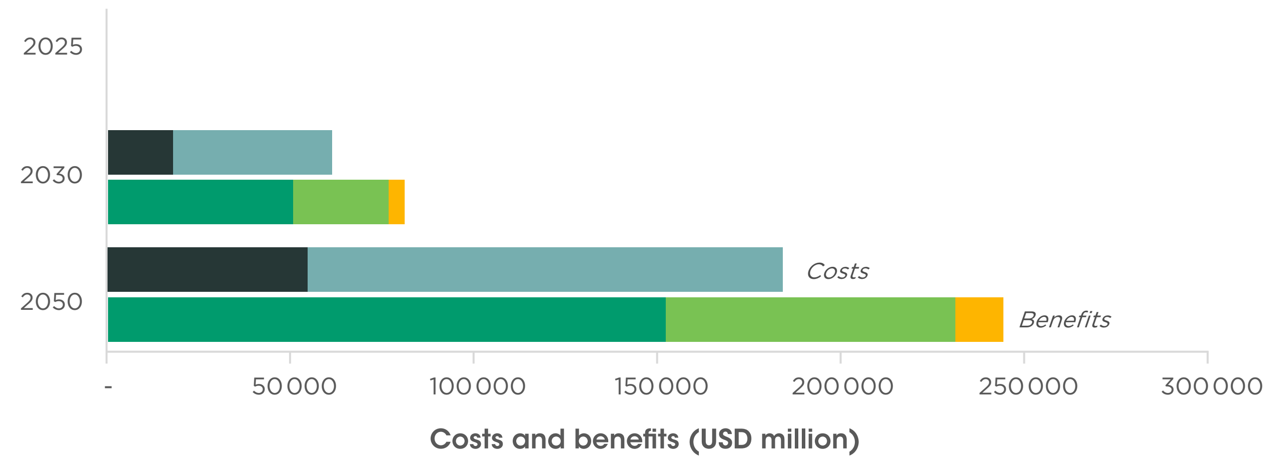


FIGURE 40: Total cost and breakdown of benefits in USD million (real value), Vietnam – pathway 3

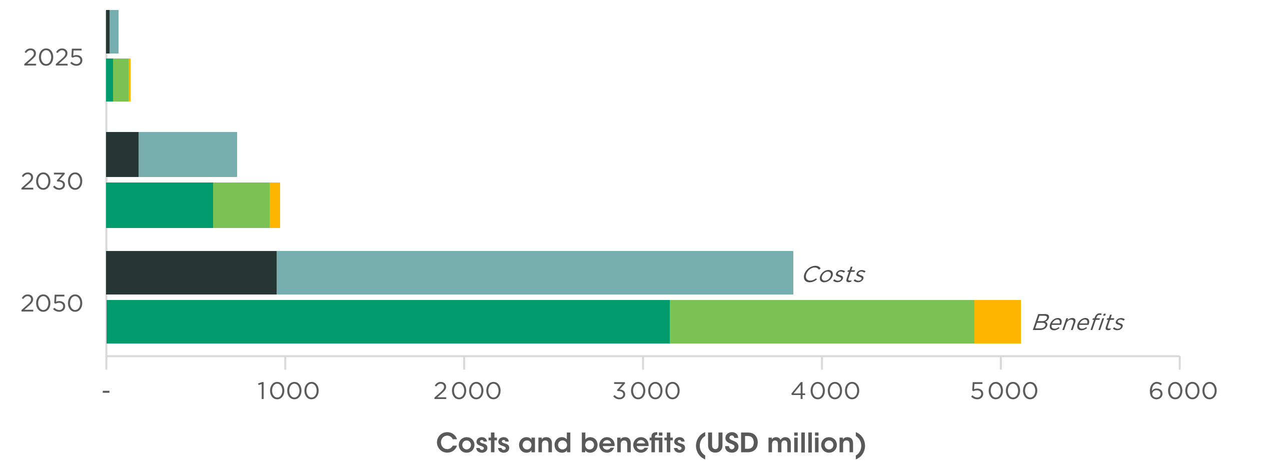
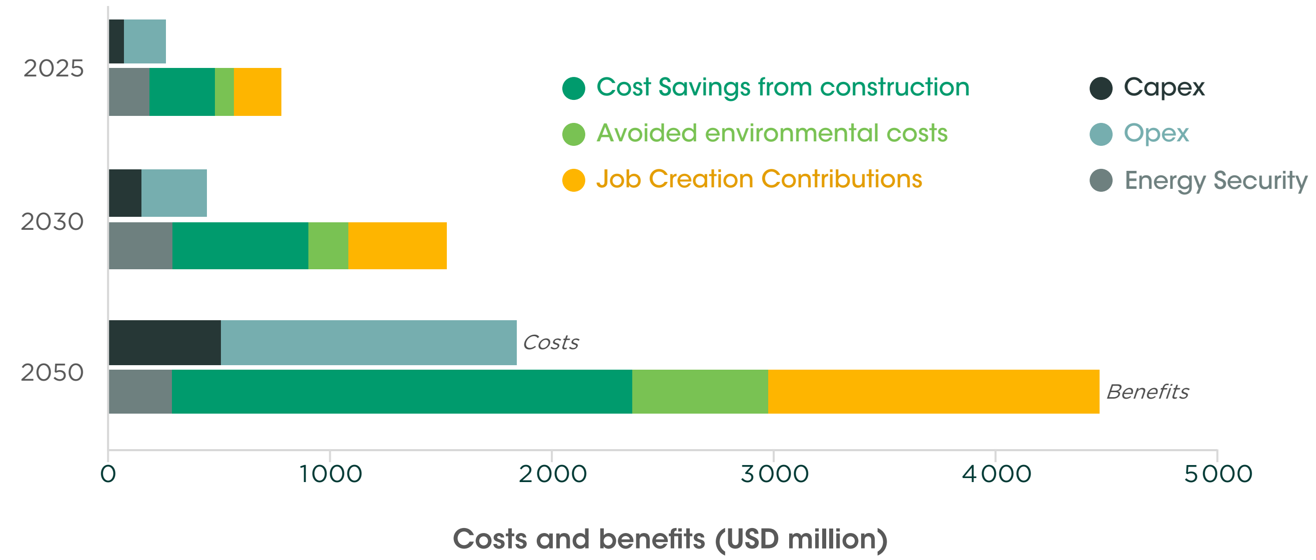


FIGURE 41: Total cost and breakdown of benefits in USD million (real value), Vietnam – pathway 4



The bulk of socio-economic benefits to be derived from the pathways stem from:

- cost savings from construction;
- avoided environmental costs;
- benefits from resilient employment; and
- improvements in energy security.

Socio-economic benefits

I. COST SAVINGS FROM CONSTRUCTION

The figures below summarise cost savings from construction realised through the implementation of the four bioenergy pathways, based on an evaluation of GWe avoided from the costs of construction and operation of a traditional fossil fuel plant. The cost of constructing biofuel plants is included in this study's cost analysis.

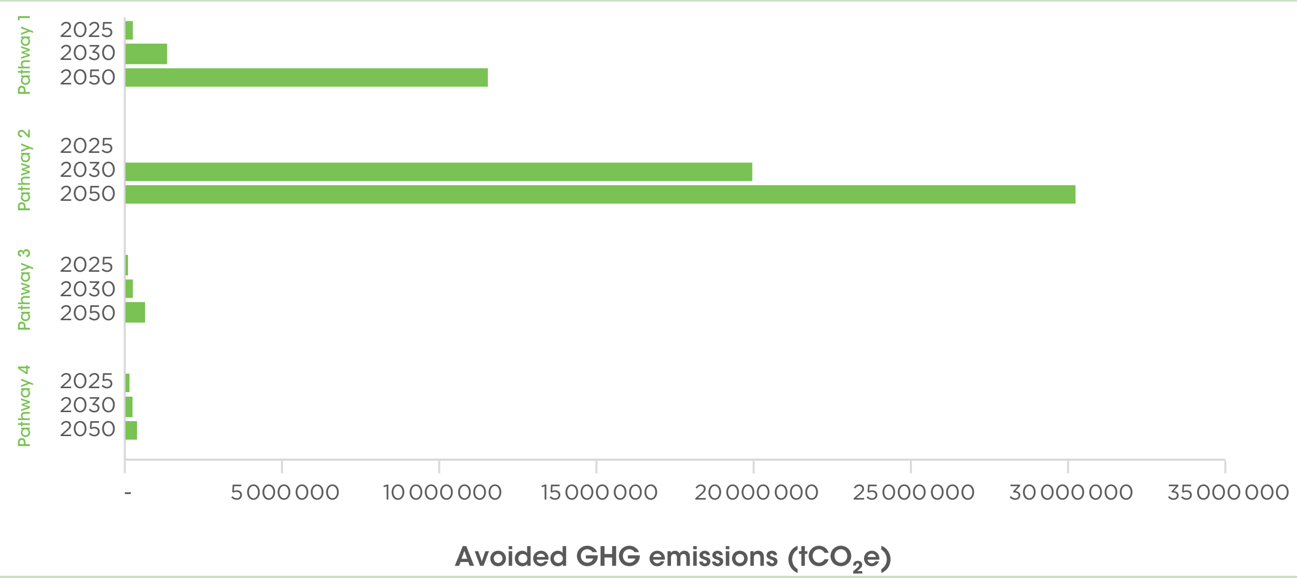
TABLE 29: Capacity of traditional fossil fuel plant saved (GWe), Vietnam

Capacity of traditional fossil fuel plant saved	2025	2030	2050
Capacity of industrial heating facilities saved (GWe)	0.2	0.7	6.8
Capacity of CHP/power plants saved (GWe)	0.02	5.7	8.6
Capacity of gasoline plants saved (million litres per day)	0.2	0.3	0.5

II. AVOIDED GHG EMISSIONS SAVINGS COST

Further socio-economic benefits can be depicted through avoided GHG emissions savings, comparing the biomass energy plants with traditional fossil fuel energy plants. The potential GHG emissions avoided for each bioenergy pathway are presented below.

FIGURE 42: Estimated GHG emissions avoided in Vietnam (tCO_2e)



This represents GHG emissions savings of approximately 12 million tCO_2e, 31 million tCO_2e, 0.7 million tCO_2e and 0.2 million tCO_2e, for pathways 1, 2, 3 and 4 by 2050, respectively.

III. BENEFITS FROM RESILIENT EMPLOYMENT (NET JOB BENEFITS[24])

By 2050, implementing these bioenergy pathways provides resilient jobs to over 50 800 Vietnamese people. The figures below summarise resilient jobs created through the implementation of the bioenergy pathways in terms of farming and non-farming jobs.

FIGURE 43: Estimated number of resilient jobs created, Vietnam – bioenergy pathway 1

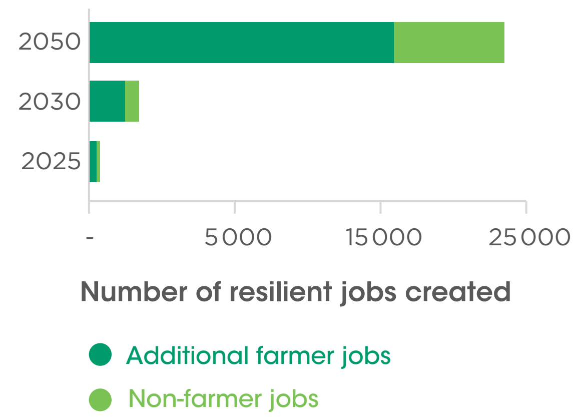


FIGURE 44: Estimated number of resilient jobs created, Vietnam – bioenergy pathway 2

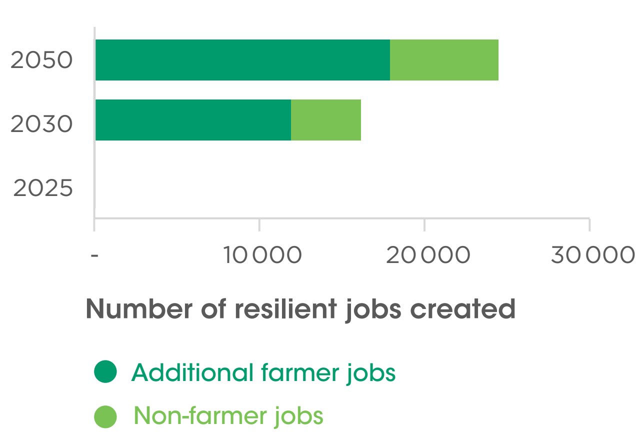


FIGURE 45: Estimated number of resilient jobs created, Vietnam – bioenergy pathway 3

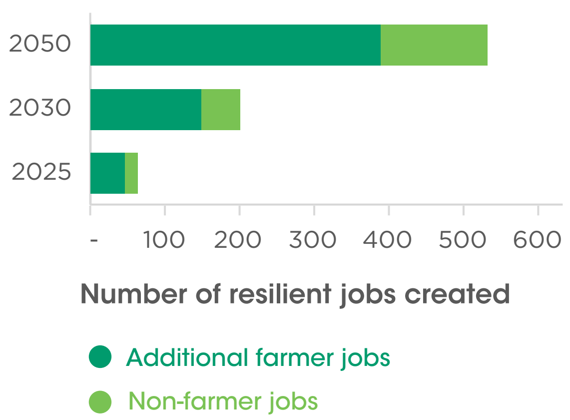
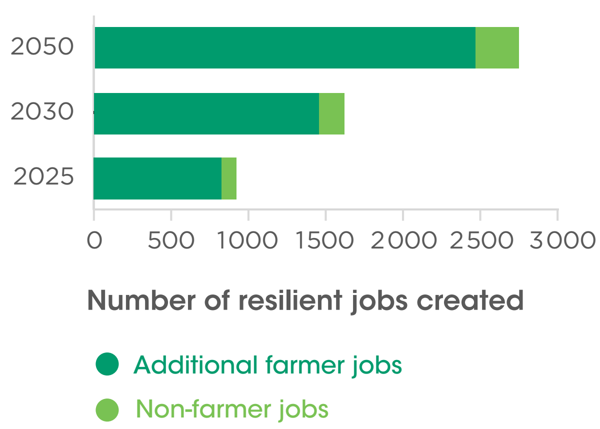


FIGURE 46: Estimated number of resilient jobs created, Vietnam – bioenergy pathway 4



24 Benefits are calculated as net job benefits, meaning the figure accounts for lost jobs in coal, oil and gas industries.

IV. IMPROVEMENTS IN ENERGY SECURITY

The figures below summarise the improvements in energy security realised through implementation of the four bioenergy pathways, stemming from decreased reliance on fossil fuel imports and costs, and the GDP impact of avoided increases in imported fuel prices.

TABLE 30: Percentage of fossil fuel imports saved, Vietnam

Percentage of fossil fuel imports saved	2025	2030	2050
Percentage of coal imports saved	1%	15%	17%
Percentage of oil imports saved	1%	2%	2%

Note that bioenergy pathway 3 is excluded from this analysis, as the pathway does not contribute to improved energy security given that Vietnam is a net natural gas exporter. Bioenergy pathway 4 provides the most significant contribution to improving bioenergy security, as the increase in bioethanol production locally directly reduces the amount of imported traditional fossil fuels required.

Summary of findings

The average annual cost required to realise the four bioenergy pathways is estimated to be around USD 2.9 billion through 2050. In this study, costs include analysing capital expenditure, as well as operations and maintenance costs. The average annual socio-economic benefits achieved through the implementation of the pathways would exceed the average annual economic costs by USD 0.5 billion through 2050, resulting in net positive gains. The consequent total socio-economic benefits for each bioenergy pathway are presented in ENPV and calculated as a BCR.

TABLE 31: Socio-economic outcomes arising for potential bioenergy pathways in 2050, Vietnam

Bioenergy pathways	Present value of total economic costs for each bioenergy pathway (in USD million)			Economic net present value of total socio-economic benefits for each bioenergy pathway (in USD million)			Benefit-cost ratio for each bioenergy pathway		
	2025	2030	2050	2025	2030	2050	2025	2030	2050
Bioenergy pathway 1 direct combustion for industrial heat generation	189	1 075	29 778	32	180	7 782	1.17	1.17	1.27
Bioenergy pathway 2 direct combustion for combined heat and power generation	-	27 179	81 844	-	3 263	9 742	-	1.12	1.12
Bioenergy pathway 3 anaerobic digestion to generate biogas for both heat boilers and CHP plants	29	304	1 606	5	63	331	1.15	1.21	1.21
Bioenergy pathway 4 fermentation to produce bioethanol and blending	113	235	795	158	292	733	2.40	2.24	1.92
Total	**331**	**28 794**	**114 023**	**194**	**3 797**	**18 588**			

Key observations from this assessment are:

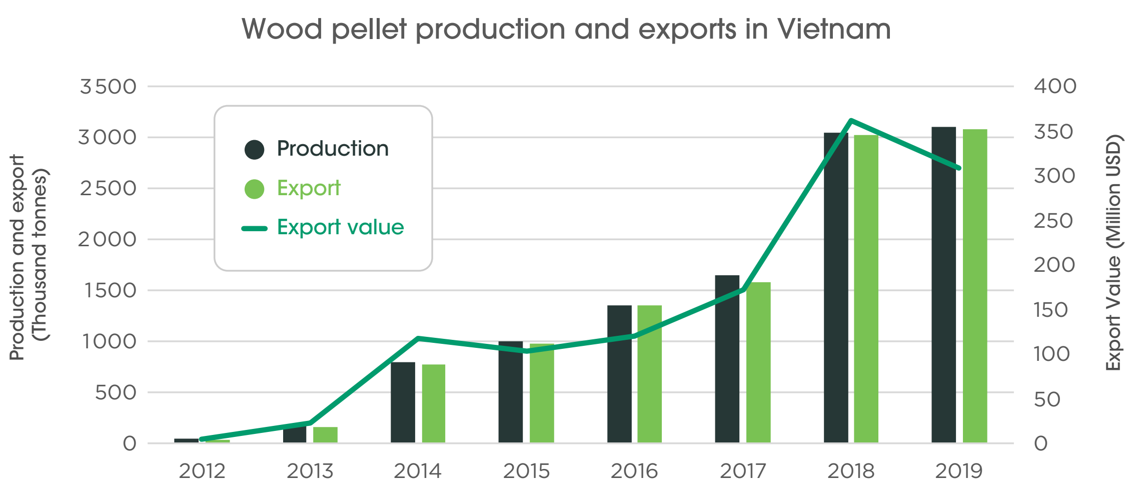
- BCR values for all bioenergy pathways are greater than 1.0, thus all bioenergy pathways would deliver strong ENPV of socio-economic benefits to Vietnam, amounting to over USD 18.5 bn of net benefits in 2050.
- Bioenergy pathway 2 offers the most significant potential socio-economic impact (ENPV of ~USD 10 bn in 2050).

BOX 7: WOOD PELLET EXPORTS FROM VIETNAM

Wood pellet exports from Vietnam have dramatically increased since the early 2010's. The boost in exports in the last decade has been triggered by the rapid expansion of installed capacity of biomass power plants in Japan and Korea as part of renewable electricity policies under FITs.

Almost all domestic production of wood pellets in Vietnam is destined for export, with export quantity and value hitting 3 023 000 tonnes and USD 362 million in 2018, respectively. This period coincided with the rapid increase of Vietnam's reliance on coal in its power mix, turning itself from a net exporter of coal to a net importer in 2015.

Although biomass can be mobilised to adjust the supply and demand gap in the renewable energy market and can be instrumental in lifting standards of living in developing countries – as demonstrated by wood pellet exports from Vietnam – this phenomenon showcases a double-edged challenge for emerging countries' decarbonisation pathways in the context of taking advantage of indigenous biomass resources



Source: FAOSTAT (2021)

Key barriers and interventions

This study reviewed Vietnam's current bioenergy using political, economic, social, environmental, technological, legal and financial (PESTEL&F) parameters, identifying key barriers to, and potential interventions required for, implementing the bioenergy pathways identified above and unlocking each pathway's potential socio-economic benefits.

Key barrier 1: Economic feasibility of required technology to convert biomass feedstock to bioenergy

- It could be difficult to introduce new technology in the Vietnamese market given the high capital costs and lack of government subsidies or incentives.
- Further incentives for the adoption of new technology are required. Although the MOIT increased feed-in-tariff to US cent 7.03/ kWh for CHP biomass plants in 2020, it is still perceived as unattractive to investors.
- Investment in advanced energy technology may not be a development strategy priority in lieu of other areas such as investment in education, support to residents below the poverty line and achieving the financial stability of public services.
- It is difficult to control fuel supply for plants due to the lack of stability and sustainability of feedstocks, and their seasonal price variations.

Key barrier 2: Institutional barriers (Cuong et al., 2021)

- Initial steps have been taken by the government to promote the development of renewable energy, including biomass energy.
- Priority credit, enterprise tax reduction, land rent reduction and PPAs have been implemented as incentives for investors.
- However, there is a lack of a powerful focal point in the government system to co-ordinate across agencies and departments.
- Policies favouring bioenergy consumption do exist but are issued in an unco-ordinated manner without sufficient investigation of the potential, demand and usage of renewable energies. Also, incentives are implemented ineffectively, especially for projects in remote areas.

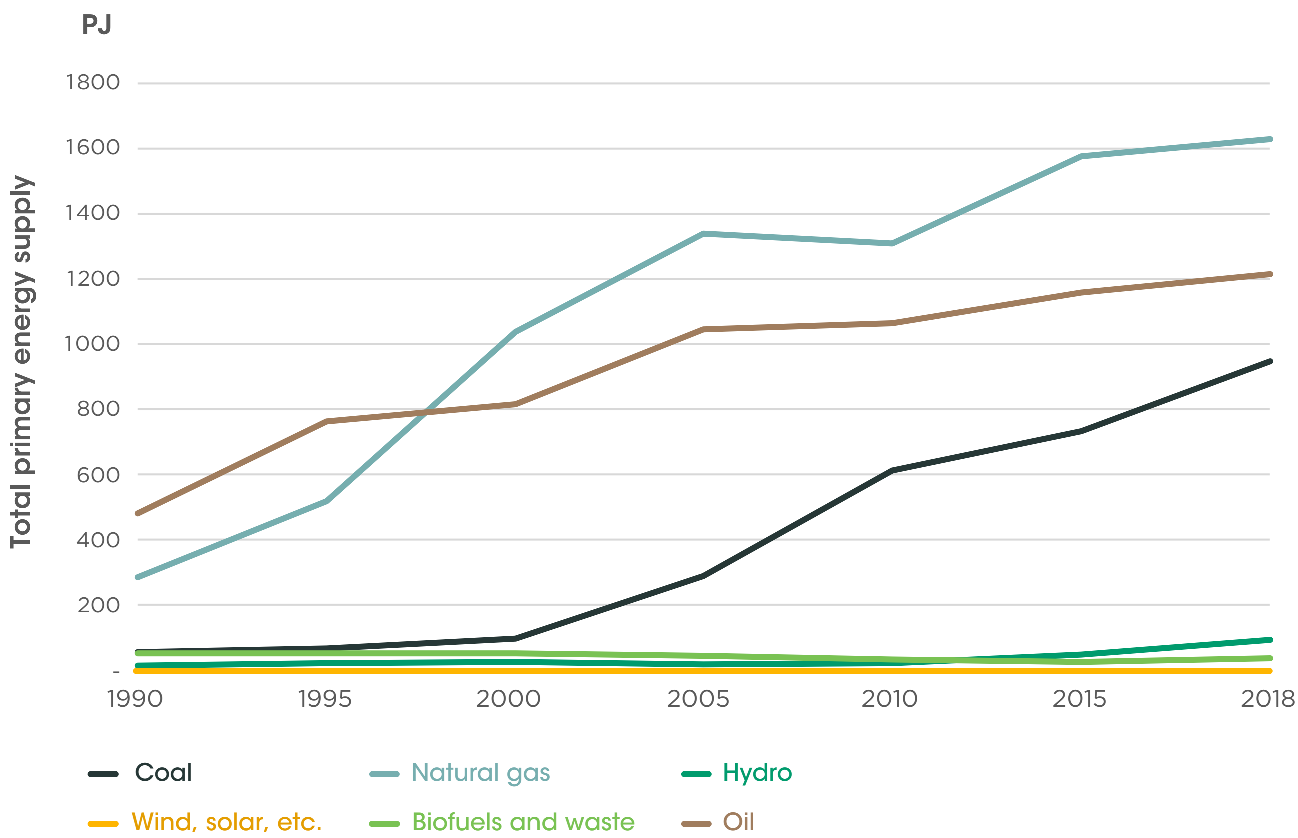
d. Malaysia

Malaysia can unlock significant socio-economic benefit potential by utilising biomass feedstock produced from its large agricultural and forestry industries.

Malaysia has a land area of 33 million ha, comprising 9 million ha of arable land and 19 million ha of forest (FAO, 2020d). The agricultural sector is identified by the Malaysian Investment Development Authority (MIDA) as a key sector, contributing 7.3% (DSM, 2020) of the country's GDP. However, Malaysia does not have any major agricultural crops that rank within the top 10 globally in terms of production quantity except for palm oil.

As presented in Figure 49 below, bioenergy is not the largest energy source among renewables in Malaysia, with a primary supply of 37 PJ in 2018. Hydro is the largest renewable energy source in Malaysia, with a primary supply of 95 PJ. Ultimately, renewable energy sources represent a negligible percentage of total energy supply in Malaysia (approximately 1%). Natural gas, oil and coal contribute the largest supplies to Malaysia's energy mix at 1 624 PJ, 1 213 PJ and 947 PJ, respectively.

FIGURE 47: Total primary energy supply in Malaysia, 1990–2018



Source: IEA (2020)

Malaysia's bioenergy policies

Malaysia is a developing country that has transformed from an economic focus on the production of raw materials in the 1970s to an emerging multi-sector economy. The oil and gas sector has been the primary source of revenue for the Malaysian Government over the last two decades (Salleh et al., 2020). As such, the national primary supply of energy continues to rely heavily on natural gas and oil, as shown in Figure 49 above.

In recent years, the Malaysian government has introduced policies to diversify the energy mix in the country with an increasing share of renewable energy. The table below depicts the initiatives taken by the Malaysian government since the early 1980s to diversify the country's energy sources (Salleh et al., 2020).

TABLE 32: Malaysia's energy policies and acts related to bioenergy initiatives, 1979–2017

Policies and acts		Key initiatives, programs or activities
1979	National Energy Policy	Provide guidelines for future energy sector development
1981	Four Fuel Diversification Policy	Ensure energy security through diversification of energy sources
2000	Five Fuel Diversification Policy	Five Fuel Diversification Strategy (2000) Centre for Education, Training and Research in Renewable Energy, Energy Efficiency and Green Technology (CETREE and GT) (2000) Small Renewable Energy Power (SREP) (2001)
2002	National Policy on the Environment	**Projects and initiatives:** • Biomass Power Generation and Generation Project (BioGen) (2002) • Malaysia Building-Integrated Photovoltaic Project (MBIPV) (2005)
2006	National Biofuel Policy	**Biofuel programs:** • B5 biodiesel programme • B7 biodiesel programme • B10 biodiesel programme • B20 biodiesel programme
2007	National Biofuel Industry Act	
2009	National Green Technology Policy	Green Technology Financing Scheme (2010)
2010	National Renewable Energy Policy and Action Plan	**Renewable energy incentives:** • Pioneer Status (PS) • Investment Tax Allowance (ITA) • Green Technology Financing Scheme (GTFS) • Renewable Energy Business Fund (REBF)
	New Energy Policy	
	National Energy Efficiency Action Plan	
2011	Sustainable Energy Development Act	Establishment of Sustainable Energy Development Authority (SEDA)
	Renewable Energy Act	**Renewable energy programs:** • Renewable Energy and Energy Efficiency Scheme (2011) • Feed in Tariff (FiT) Scheme (2011) • Net Energy Metering Scheme (2016) • Large-Scale Solar PV Project (2016)
	National Biomass Strategy 2020	Development of biomass-based industries by capitalising on the high-value opportunities available from biomass generated from agricultural, forestry, dedicated biomass crops and municipal waste
2017	National Green Technology Masterplan 2017–2030	Latest framework

Although these policies have helped Malaysia diversify its energy mix, the country will require further initiatives if it is to reach its national target of increasing the share of renewable energy to 20% by 2025. The government hopes that the construction of Biohubs will assist the country in reaching their aspirational targets.

Introduction of the biohub concept in Malaysia to reach energy mix targets

A biohub is a system where local ministries and private businesses co-operate to recover the highest value from regional waste streams, offering new industry, revenue generation and bioenergy opportunities (Utilitas, 2017).

Biohubs potentially provide the following environmental benefits:

- recycling waste into higher value uses;
- reducing waste-related odour;
- reducing waste going to landfill;
- generating reliable and dispatchable renewable electricity;
- producing non-fossil-based fuels, plastics, chemicals and fertilisers;
- fitting in with existing infrastructure and community demand; and
- sustainable economic development and job creation.

The Sarawak Biohub Port and Industrial Estate development is a renewable energy project that is part of Malaysia's National Biomass Strategy (NBS) initiative and is expected to launch in the first quarter of 2021. The project is a strategic collaboration between Agensi Inovasi Malaysia, Regal Lands Sdn Bhd, Bintulu port Holdings Bhd, and the Port of Rotterdam. The development will be located on 2 500 ha of land between Bintulu and Samalju with an estimated development cost of RM 20 billion over 10 years (Malay Mail, 2020).

The development seeks to integrate bioport infrastructure, carbon neutral bio manufacturing clusters and clean transportation networks and logistics, supported by transparent and traceable biomass and waste feedstock for the new bioindustries (HCH, 2020). It is estimated that Sarawak stands to capture approximately RM 4.8 billion in additional revenue per year once the development is operational, creating 35 000 new green jobs and generating approximately RM 18 billion in investments (Azman, 2020).

Woody biomass: Next bioenergy potential for Malaysia after palm oil

Malaysia needs to seek out biomass feedstock with untapped potential to diversify its conversion pathways and meet its aspirational targets in line with the biohub concept. For example, the National Biomass Strategy 2020 lays the foundations for Malaysia to capitalise on its biomass by channelling it into higher value downstream uses. As the second largest producer of palm oil following Indonesia, policies implemented by the Malaysian government to date have focused on this sector to capitalise on the large amount of oil palm by-products produced in the country (Salleh et al., 2020).

BOX 8: COLLECTION OF BIOMETHANE FROM PALM OIL BIOMASS
Malaysia has a theoretical potential to extract 424 million tCO_2e of biomethane from palm oil residues every year – 2.6 times more than Malaysia's annual GHG emissions. See Appendix A for further details of the analysis conducted.

Malaysia produces more than 103 million tonnes of biomass, including agricultural waste, forest residues and municipal waste (Ozturk et al., 2017), some of which is suitable for conversion to biofuel. The National Biomass Strategy 2020 identifies woody biomass as a feedstock with high potential; as much as 2.7 million tonnes of woody biomass is available in Sarawak alone (predominantly from existing plantations).

For these reasons, this study has only analysed one potential bioenergy pathway, focusing on woody biomass that can be sourced from Malaysia's plantation forests. The bioenergy pathway analysed, and the associated socio-economic benefits, are presented in this section, and have been identified in accordance with the three-step approach outlined in the introduction.

Bioenergy pathways

Identifying available biomass feedstocks in Malaysia

I. ACACIA AND RUBBER

Malaysia has a thriving forest sector, producing approximately 14 million m^3 of industrial roundwood for sawn timber, plywood, pulp and other fibre materials, and another 2.4 million m^3 of wood fuel mainly for traditional cooking in 2019 (FAOSTAT, 2021). Malaysia has one of the world's largest areas of certified tropical forest (The Star, 2011). The socio-economic benefits derived from the timber products produced from this rainforest represented approximately 6% of the country's GDP in 2019. Malaysia's timber and timber-related exports were valued at RM 23 billion in 2019 (Yusof, 2019).

For Malaysia, this study focuses on acacia and rubber as potential biomass feedstocks that can be sourced from planation forests, as the sustainability assessment of the management of natural forests requires more in-depth analysis. Malaysia has a total rubber area of 1 million ha and is the world's seventh largest producer of natural rubber. Planting of acacia experienced significant growth in the early 1980s as the Compensatory Forest Plantation Programme (CFPP) was initiated by the Forest Department in Peninsular Malaysia. The CFPP sought to increase the yield of general utility saw logs (Lim et al., 2004).

TABLE 33: Malaysia's potential biomass energy sources – selected, available bioenergy feedstock

Type of feedstock	Quantity available (million tonnes)		
	2025	2030	2050
Acacia	5.6	6.0	6.3
Rubber	4.6	4.9	5.2
Total	**10.3**	**10.9**	**11.5**

Source: IRENA (2017a)[25]

It is worth noting that demand for conventional uses of the acacia for pulp and paper, and rubber for timber and furniture, are all deducted from the total quantity available.

Identifying collectible biomass feedstocks in Malaysia

For woody biomass, collection of harvest residue, or logging residue, involves transportation challenges due to its bulky nature. Therefore, processing residue should be primarily mobilised to meet power and heat demand at wood processing plants, with only surplus residues becoming available for external use.

On the other hand, the allowable annual cuts from acacia plantations may be raised within the increment capacity of acacia trees. In other words, as long as the total carbon stored in forest stands does not shrink at the landscape level, adoption of intensive management will make woody biomass more readily available for energy markets and other applications.

This study assumes the collection ratio for applicable feedstock[26] out of the total potential will increase from 30% to 50% and 90% in 2025, 2030 and 2050, respectively, for woody biomass (presented in the table below).

25 The estimation of biomass quantity available is undertaken based on Biofuel Potential in Southeast Asia (IRENA, 2017a). It is assumed that the total availability corresponds to the annual woody biomass increment multiplied by energy wood share.

26 The applicable feedstock excludes conventional uses of the residues for animal feed and bedding, the acacia for pulp and paper, and rubber for timber and furniture.

TABLE 34: Malaysia's potential biomass energy sources – selected, collectible bioenergy feedstock

Type of feedstock	Quantity collected for bioenergy feedstock (million tonnes)		
	2025	2030	2050
Acacia	1.7	3.0	5.7
Rubber	1.4	2.4	4.7
Total	**3.1**	**5.4**	**10.4**

The increasing quantity of biomass feedstock available over each of the horizons studied directly correlates to an increasing amount of collectable biomass feedstock. Other factors that contribute to this increase include: improvements in logistics management; improvements in stock-pile management; and improvements in surrounding infrastructure.

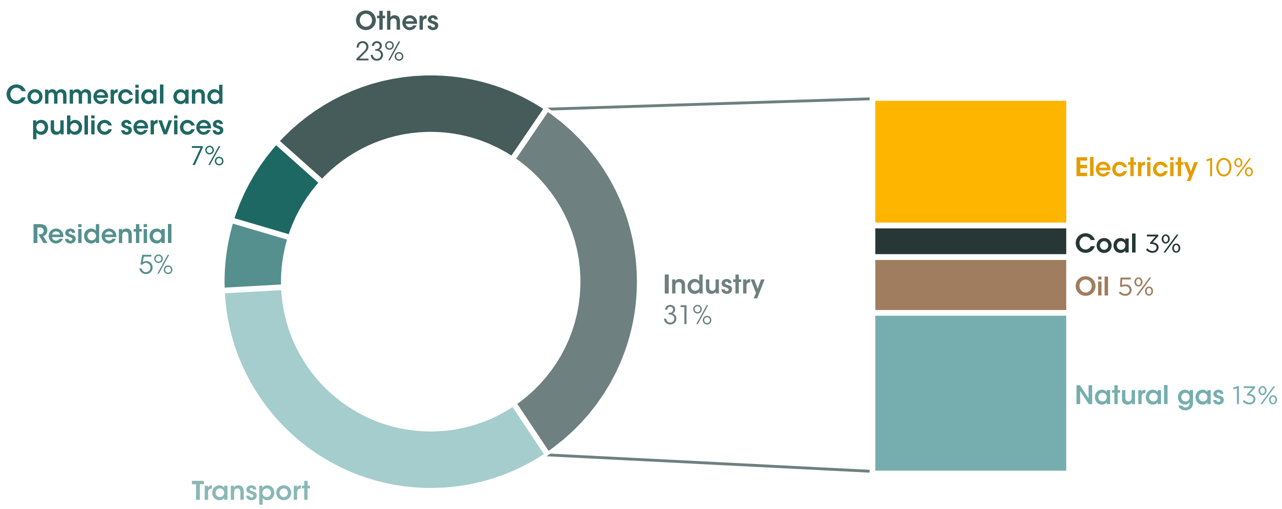
The collectible quantity of biomass feedstock is converted to petajoules (PJ) in the table below and presented as the estimated potential primary bioenergy supply that Malaysia would have available for each identified biomass feedstock.

TABLE 35: Malaysia's potential primary bioenergy supply – selected, collectible bioenergy feedstock

Type of feedstock	Primary bioenergy supply (PJ)		
	2025	2030	2050
Acacia	32.1	56.6	108.1
Rubber	26.4	46.5	88.9
Total	**58.6**	**103.1**	**197.0**

Malaysia's energy mix

FIGURE 48: Malaysia's energy mix and usage of conventional fossil fuels in 2017



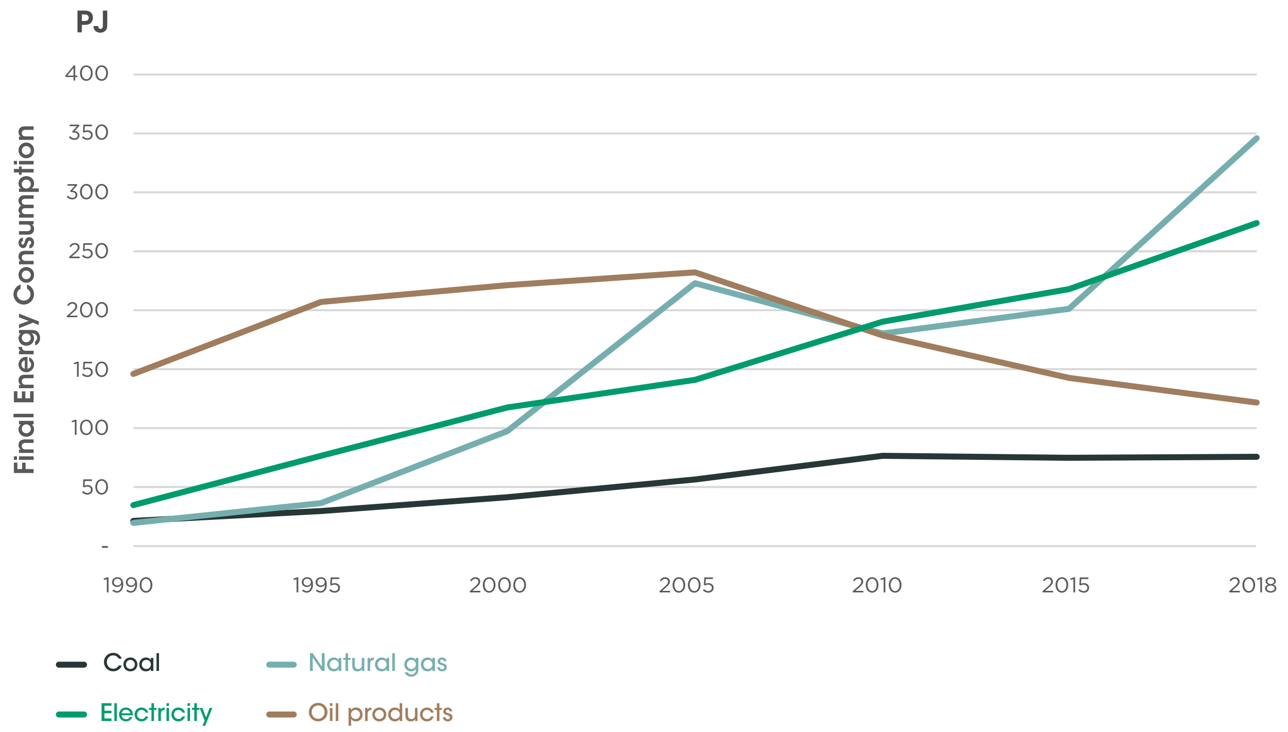
Since only woody biomass was discussed for Malaysia, the main target of end-use applications is the industry sector. The industry sector consumes approximately 31% of Malaysia's energy (see Figure 48) and provides concentrated nodes of energy demand where fuel substitutions should be facilitated in moving toward a low carbon economy.

The energy demand for the industry sector in Malaysia has been increasingly met by natural gas and electricity, while the use of biomass for industry has not been recorded since 2009 (see Figure 49 below).

Electricity generation is predominantly sourced from natural gas and coal. Hydro is also expected to play a minimal role in the power mix of the country, as shown in the figure below. Malaysia positions itself as a major exporter of oil and natural gas, and reliance on natural gas in the energy mix is therefore an economically justifiable option. In contrast, Malaysia is a net importer of coal and therefore coal-fired power plants represent a substitutable market for wood-derived bioenergy.

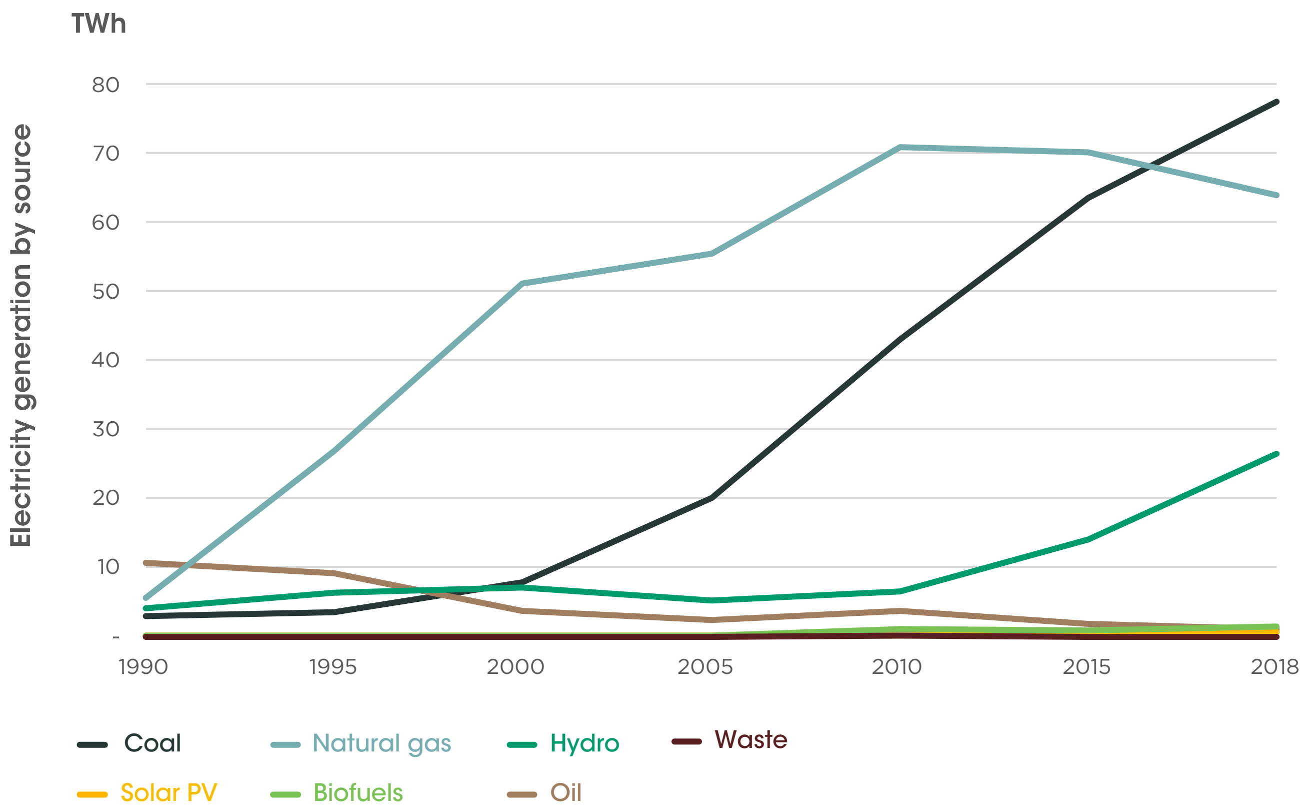
The economic rationale for positioning biomass-based power generation as a substitute for coal is the fact that only minor modifications to existing facilities are required for the fuel switching to biomass. Also, the phased replacement of coal can be planned by adopting co-firing without risking existing facilities becoming stranded assets (Gent et al., 2017). In addition, biomass-based CHP plants can provide both clean electricity and renewable heat to meet demand in surrounding areas, thus significantly improving overall energy efficiency.

FIGURE 49: Malaysian industry sector – final energy consumption by source



Source: IEA (2020)

FIGURE 50: Sourced of electricity generation in Malaysia, 1990–2019

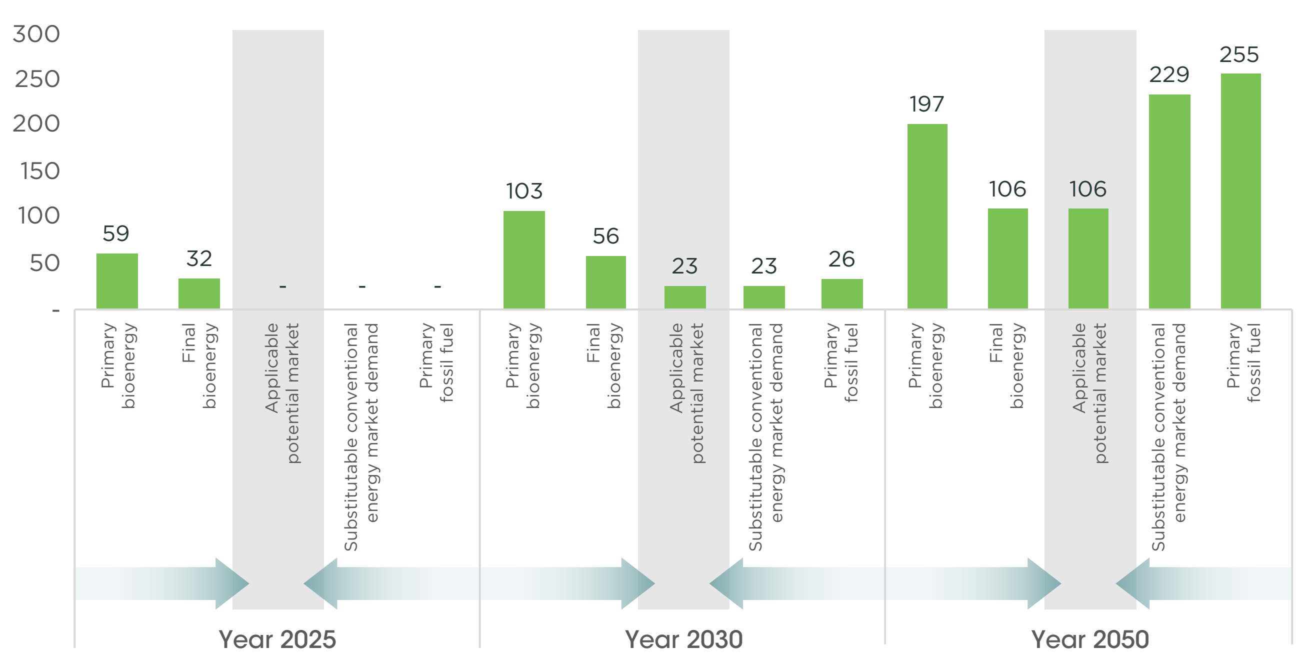


Source: IEA (2020)

Bioenergy pathways and substitutable markets identified in Malaysia

The consideration of both supply and demand in Malaysia's energy mix results in the identification of acacia and rubberwood for direct combustion for combined heat and power generation as the most probable bioenergy applications. Substitutable markets for biomass have been estimated for three different horizons, namely 2025, 2030 and 2050.

FIGURE 51: Bioenergy pathways in Malaysia (2025, 2030 and 2050) in PJ



The total applicable potential market in Malaysia is estimated to be around 23 PJ in 2030, and 106 PJ in 2050.

Bioenergy pathway 1 (direct combustion for combined heat and power generation) focuses on replacing coal with biomass in CHP plants. The total consumption of coal in industry in Malaysia is around 75 PJ (IEA, 2020). This bioenergy pathway selects coal used in CHP plants as a market where bioenergy can make an impact as a substitute energy source. Forestry biomass from acacia and rubber was also identified as a commercially viable substitute energy source for this pathway.

In the short term, this study assumes there will not be any CHP capacity built and completed by 2025. In the medium and long terms, with new-build biomass CHP plants, this analysis assumes that 15% of black coal fired heat boilers or equivalent amount in power plants will be replaced by biomass-fuelled CHP plants in 2030, increasing to 75% in 2050. The substitutable market is evaluated at 23 PJ and 106 PJ by 2030 and 2050, respectively.

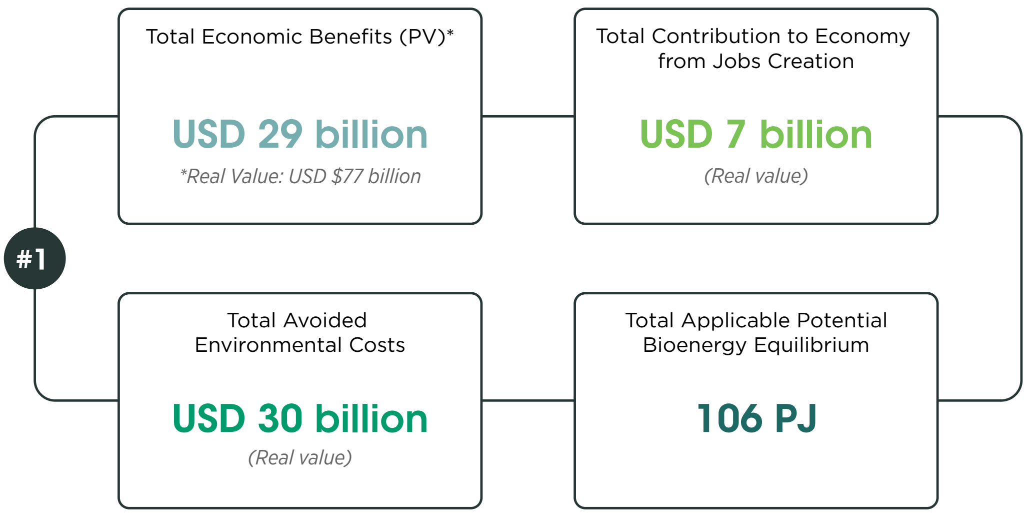
Economic assessment

Bioenergy economics is used to analyse the quantum of socio-economic benefits that can be unlocked through successful implementation. The bioenergy pathway is compared with its substitutable market in order to determine how much of the socio-economic value can the bioenergy replace:

- Bioenergy pathway 1 (Direct Combustion for combined heat and power generation) compares the economic costs and benefits of direct combustion of wood pellets or chips produced from acacia and rubber against black coal for traditional heat and power plants.

A summary of findings from our bioenergy economics analysis is presented in the following dashboard and summary table.

FIGURE 52: Summary dashboard for bioenergy pathway 1 in Malaysia, 2050



Pathway 1: Direct Combustion for combined heat and power generation

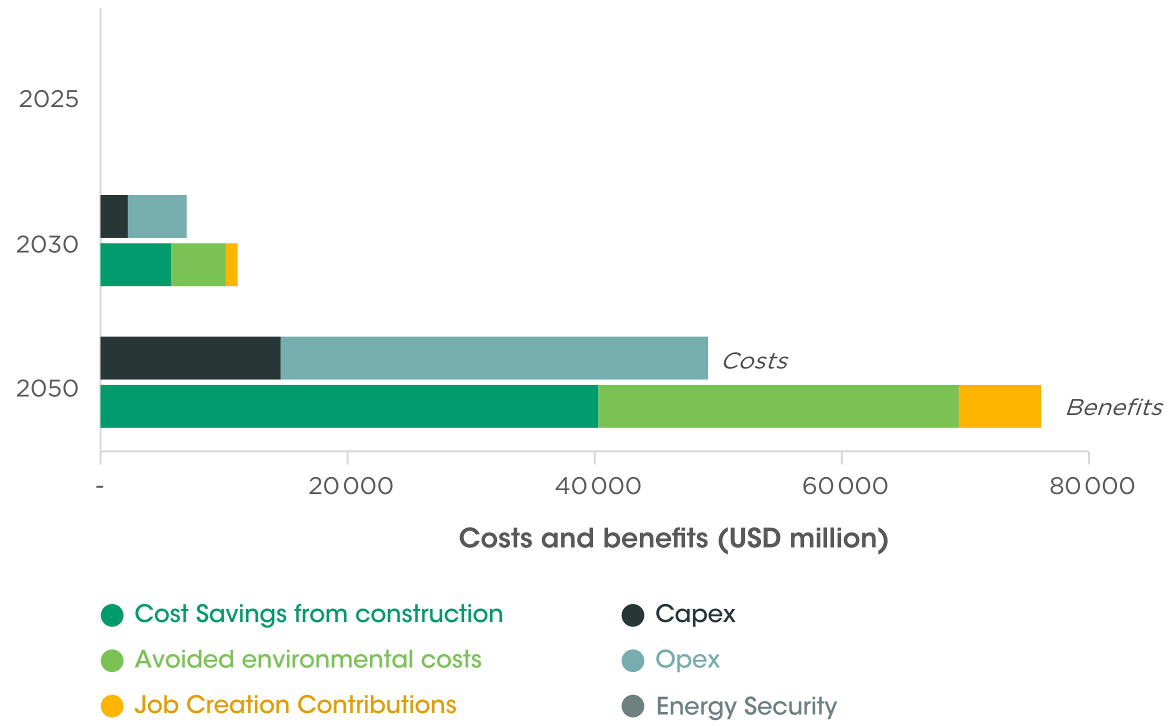
TABLE 36: Summary of findings for bioenergy pathway 1, Malaysia

Type of feedstock	Type of process	Total applicable potential bioenergy equilibrium (2050)		BCR (2050)	Total net present value of economics benefits (NPV) in USD bn (2050)
Acacia and rubber	Direct combustion for combined heat and power generation	106.4	PJ	1.26	6.2

This pathway results in a BCR above 1 and results in impacts on the economy of Malaysia amounting to approximately USD 6.2 billion of net present value of socio-economic benefits in 2050, creating over 12 600 new resilient jobs and saving around 22 million tonnes of GHG emissions per year.

The socio-economic costs and benefits are expressed below in real value (USD million) for 2025, 2030 and 2050, adjusted for economic inflation.

FIGURE 53: Total cost and breakdown of benefits in Malaysia, in USD million (real value)



The bulk of the socio-economic benefits to be derived from the pathways stem from:

- cost savings from construction;
- avoided environmental costs;
- benefits from resilient employment; and
- improvements in energy security.

Socio-economic benefits

I. COST SAVINGS FROM CONSTRUCTION

The figures below summarise the cost savings from construction realised through the implementation of the identified bioenergy pathway. Cost savings from construction are based on an evaluation of the GWe avoided when compared to the construction and operation of a traditional fossil fuel plant:

TABLE 37: Capacity of traditional fossil fuel plant saved (GWe), Malaysia

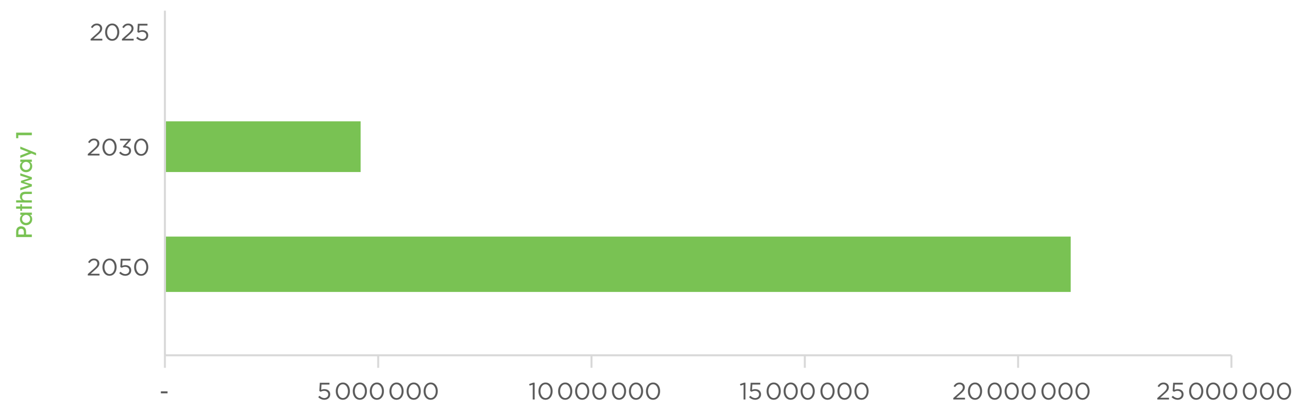
Capacity of traditional fossil fuel plant saved	2025	2030	2050
Capacity of CHP/power plant saved (GWe)	-	0.9	4.2

II. AVOIDED GHG EMISSIONS SAVINGS

Further socio-economic benefits can be depicted through avoided GHG emission savings by comparing biomass energy plants with traditional fossil fuel energy plants.

The potential GHG emissions avoided by pursuing the bioenergy pathway amount to 22.5 million tCO_2e by 2050 and are presented below.

FIGURE 54: Estimated GHG emissions avoided in Malaysia (tCO_2e)

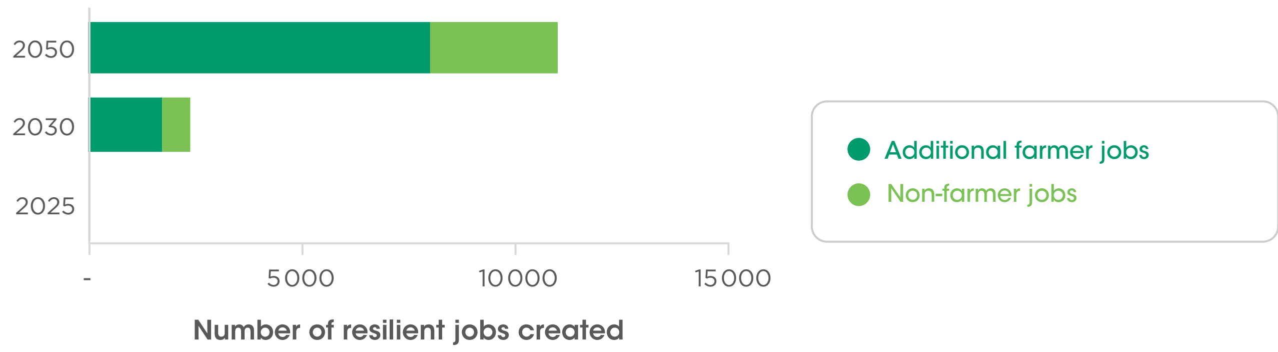


Malaysia has recognised its rising GHG emissions since 2000, a trajectory that reflects the need to meet its increasing demand and the requirements of economic growth (Philip et al., 2020). Although solely introducing these bioenergy pathways would not be sufficient for Malaysia to halt its rising GHG emissions and meet its 2015 Paris Climate Agreement targets, the resultant GHG emissions savings will contribute to the country's success in reaching its commitments.

III. BENEFITS FROM RESILIENT EMPLOYMENT (NET JOB BENEFITS[27])

Estimating the number of resilient jobs created through the implementation of this bioenergy pathway is a useful measure of socio-economic benefits; by 2050, it will result in the provision of resilient jobs for around 12 600 Malaysians. The figure below summarises the estimated resilient farming and non-farming jobs created.

FIGURE 55: Estimated number of resilient jobs created in Malaysia



IV. IMPROVING ENERGY SECURITY

The figures below summarise the improvements in energy security realised through implementation of the bioenergy pathway.

TABLE 38: Estimated percentage of coal imports saved (GWe), Malaysia

	2025	2030	2050
Percentage of coal import saved	-	1%	2%

In addition to the benefits quantified above, implementing bioenergy projects will also help countries mitigate the risk of energy import supply shortages.

Summary of findings

The average annual cost of realising the bioenergy pathway is estimated to be around USD 0.8 billion through 2050. In this study, costs include capital expenditure, operations and maintenance costs. The average annual socio-economic benefits achieved through the implementation of the pathway would exceed average annual economic cost by USD 0.2 billion through 2050, resulting in net positive gains.

27 Benefits are calculated as net job benefits, meaning the figure accounts for lost jobs in the coal, oil and gas industries.

Utilising the analysis conducted above, the consequent total socio-economic benefits for the bioenergy pathway is presented in ENPV and calculated as a BCR:

TABLE 39: Socio-economic outcomes arising from the bioenergy pathway, Malaysia

Bioenergy pathways	Present value of total socio-economic costs for each bioenergy pathway (in USD million)			Economic net present value of total socio-economic benefits for each bioenergy pathway (in USD million)			Benefit-cost ratio for each bioenergy pathway		
	2025	2030	2050	2025	2030	2050	2025	2030	2050
Bioenergy pathway 1 direct combustion for combined heat and power generation	-	3 408	23 309	-	906	6 170	-	1.27	1.26

The key observations from this assessment are:

- BCR for this bioenergy pathway is greater than 1.0. It would deliver a strong ENPV of socio-economic benefits to Malaysia, amounting to over USD 6.2 bn of net benefits in 2050;
- the bioenergy pathway shows significant increases in ENPV over the short-, medium- and long-term horizons, as bioenergy production methodologies become more efficient and commercially viable; and
- the increasing ENPV and positive BCR provides an idea of the socio-economic benefits that could be unlocked by implementing this pathway, which merits being prioritised to more quickly lock-in the associated benefits based purely on the socio-economic cost–benefit assessment.

Key barriers and interventions

This study reviewed Malaysia's current bioenergy framework using political, economic, social, environmental, technological, legal and financial (PESTEL&F) parameters to identify key barriers to implementation and the interventions required to mitigate these barriers and unlock the pathway's potential socio-economic benefits.

Key barrier 1: Lack of agreement between policy makers and concerned departments

- A key barrier in the past for the Malaysian government in reaching the proposed targets is a lack of agreement between policy makers and line ministries regarding the strategies that are best suited to reaching the nation's proposed targets.
- At least seven major ministries were involved in renewable energy planning during the 9th Malaysia Plan, each with equal responsibility.

- The government's inability to meet policy targets in the past is partially attributable to a lack of co-ordination; the government took initiatives in the 10th and 11th Malaysian Plans to make co-ordinated progress on its renewable energy agenda.
- Enforced in 2011, the Renewable Energy Act aims to accelerate the contribution of renewable energy to Malaysia's electricity generation mix (including solar PV, biomass, biogas and mini hydro).
- Better co-ordination among agencies and departments, including the forest sector and natural rubber sector, will be key to further successes.

e. Myanmar

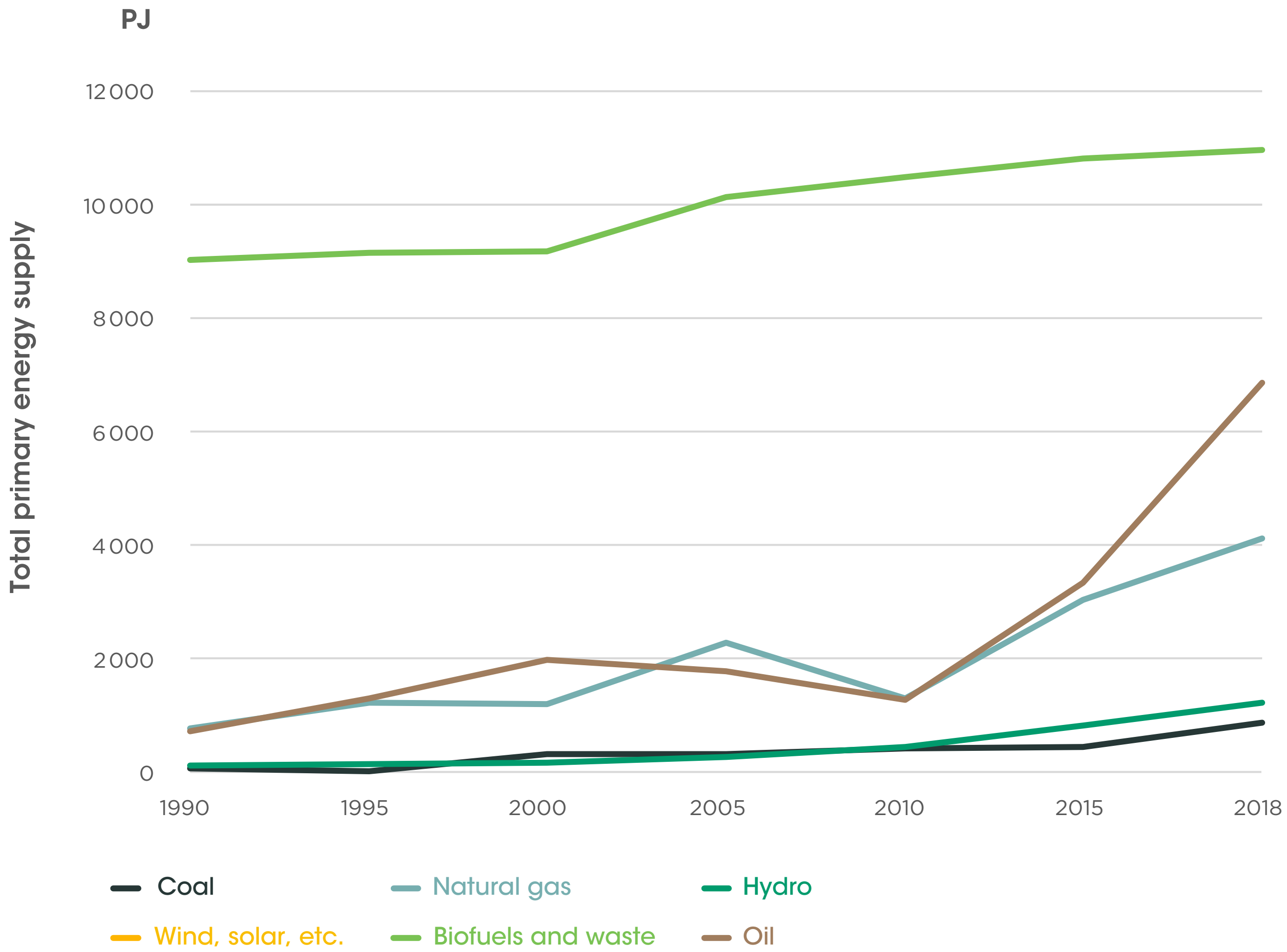
Half of Myanmar's energy needs are met by bioenergy – particularly woody biomass – but the use of biomass feedstock comes at the expense of deforestation and forest degradation.

Myanmar is the 10th largest country in Asia by area and is bordered by emerging economies such as India and China. It is a biodiverse country and is home to some of the largest intact natural ecosystems in the region, but the remaining ecosystems are under threat from land use intensification and over-exploitation.

Myanmar had an average annual net loss of forest in 2010–2020 of 290 000 ha – the seventh highest in the world (FAO, 2020e). Such a high rate of deforestation has been associated with the country's dependence on wood fuels, with bioenergy contributing 75% of the total primary energy supply in 2010 and 46% in 2018. Annual wood fuel production in Myanmar amounted to 38 million m^3 in 2018 – comparable to 40 million m^3 in Indonesia (FAOSTAT, 2021), which has more than three times the forest cover. While land use change and forestry accounts for more than 80% of the country's total GHG emissions, with energy related GHG emissions only having a marginal share, forestry activities are closely associated with energy use – especially for cooking in the residential sector.

As presented in Figure 56 below, bioenergy is the largest energy source in Myanmar with a primary supply amounting to 458 PJ in 2018. Bioenergy has consistently been the major source of energy in Myanmar, although consumption of oil has increased exponentially since 2011.

FIGURE 56: Total primary energy supply in Myanmar, 1990–2018



Source: IEA (2020)

While energy demand continues to rise, Myanmar risks relying more on fossil fuels such as natural gas and oil in its energy mix. To set a course for a climate compatible pathway, it is of critical importance that this trend be reversed and that bioenergy remains a fundamental energy source in Myanmar.

Bioenergy pathways

Identifying available biomass feedstocks in Myanmar

I. WOODY RESIDUES

As depicted in Figure 56 above, bioenergy plays a central role in Myanmar's energy supply. Given its agriculture-based economy and 32.2 million ha of forest cover (Tun and Juchelková, 2019), biomass has the potential to continue playing a central role in the country's energy supply. Myanmar is the world's seventh largest producer of rice and tenth largest producer of coconut and natural rubber (FAOSTAT, 2021). While several modern bioenergy demonstration projects – particularly in the area of rice husk power generation – have made inroads in the last five years, most bioenergy use today remains outside the modern energy sector. Often wood fuels collected from nearby forests provide the sole energy source for cooking and energy consumption in residential rural areas that accounts for more than half of Myanmar's energy consumption (Emmerton et al., 2015). The high consumption of wood-fuel in rural areas is placing severe stress on forests through fuel-wood collection and charcoal production (Sovacool, 2013).

Heat demand for cooking in rural communities is expected to be increasingly met by electricity as access is improved. Combined with the adoption of energy efficient cookstoves, the modernisation of the energy system in the residential sector will necessitate the modernisation of forest biomass utilisation.

To assist in mitigating Myanmar's high rate of deforestation (FAO, 2020e) whilst capitalising on its large biomass potential in the forestry sector, this study analyses the potential benefits from utilising woody residues for biofuel production.

TABLE 40: Myanmar's potential biomass energy sources – selected, available bioenergy feedstock

Type of feedstock	Quantity available (million tonnes)		
	2025	2030	2050
Woody residues	1.7	1.8	1.9

Source: Tun et al. (2019)

Identifying collectible biomass feedstocks in Myanmar

As biomass feedstock becomes gradually available over time, the collectible quantity also increases. Other factors that contribute to this increase include improvements in logistics management, stock-pile management and surrounding infrastructure.

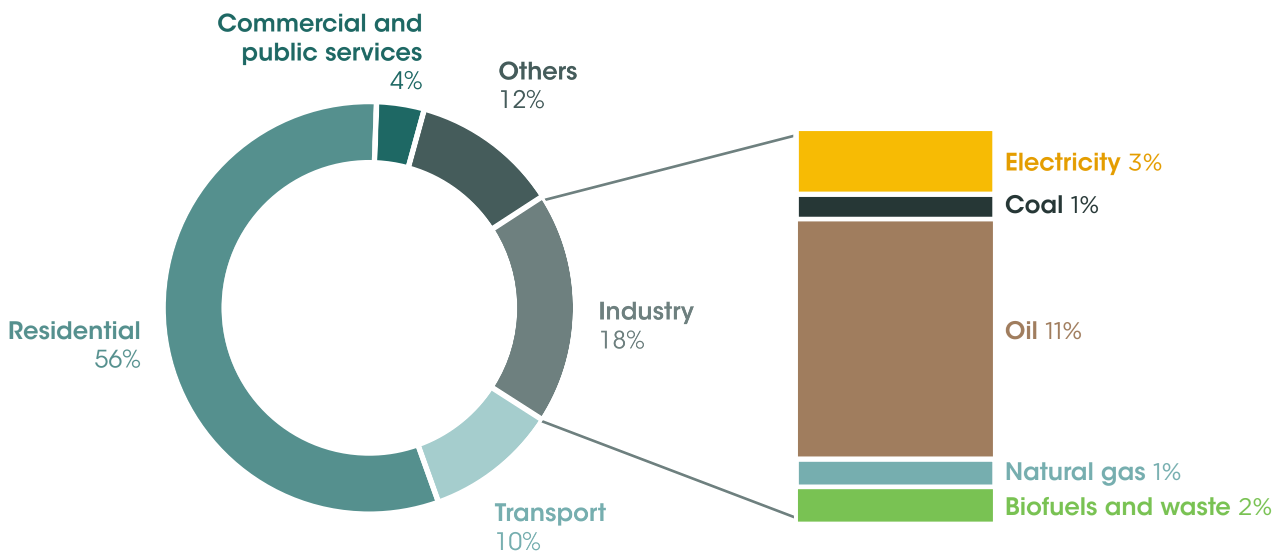
This study assumes the collection ratio for applicable feedstock will increase from 30% to 50% and 90% in 2025, 2030 and 2050, respectively, for woody biomass (refer to the table below).

TABLE 41: Myanmar's potential biomass energy sources – selected, collectible bioenergy feedstock

Type of feedstock	Collectible bioenergy feedstock (million tonnes)		
	2025	2030	2050
Woody residues Mt	0.5	0.9	1.7
Woody residues PJ	9.9	17.4	33.2

Myanmar's energy mix

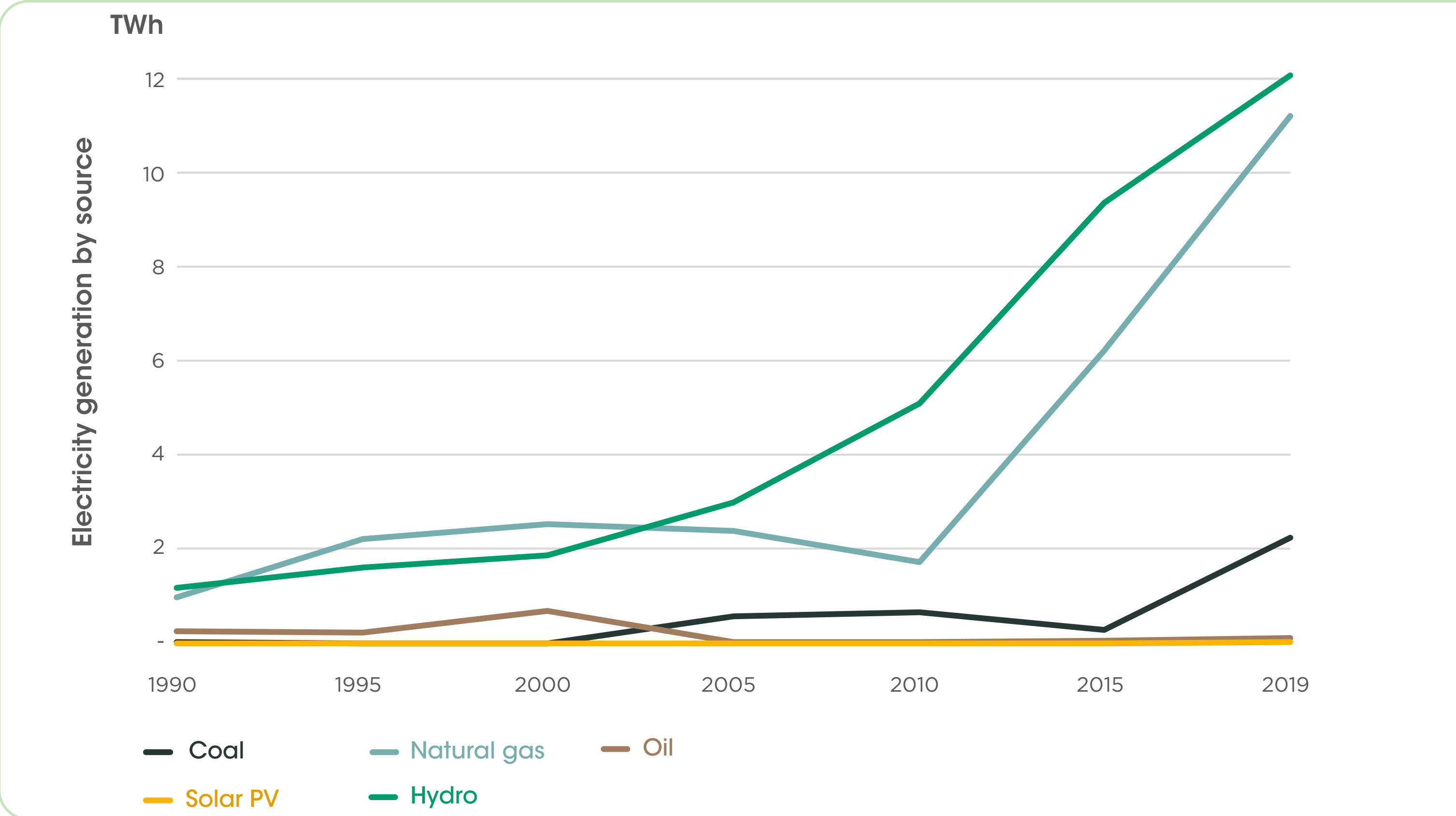
FIGURE 57: Myanmar's current energy mix and usage of conventional fossil fuels



Since only woody biomass was discussed for Myanmar, the main target of end-use applications is the industry sector, which consumes approximately 28% of Myanmar's energy (see Figure 57) and provides concentrated nodes of energy demand where fuel substitutions should be facilitated in a move toward low carbon economy. The residential sector currently consumes the largest amount of energy, with wood fuel being combusted in residential rural areas.

Figure 58 below presents Myanmar's sources of electricity generation from 1990 to 2019. To date, biofuels have not played a significant role in electricity generation. The largest energy source in the power mix is hydro. In 2019, hydropower contributed approximately 12 TWh, representing almost 50% of the country's electricity generation. Natural gas and coal are the two other major sources of Myanmar's electricity generation at 11 TWh and 2 TWh, respectively.

FIGURE 58: Sources of electricity generation in Myanmar, 1990–2019



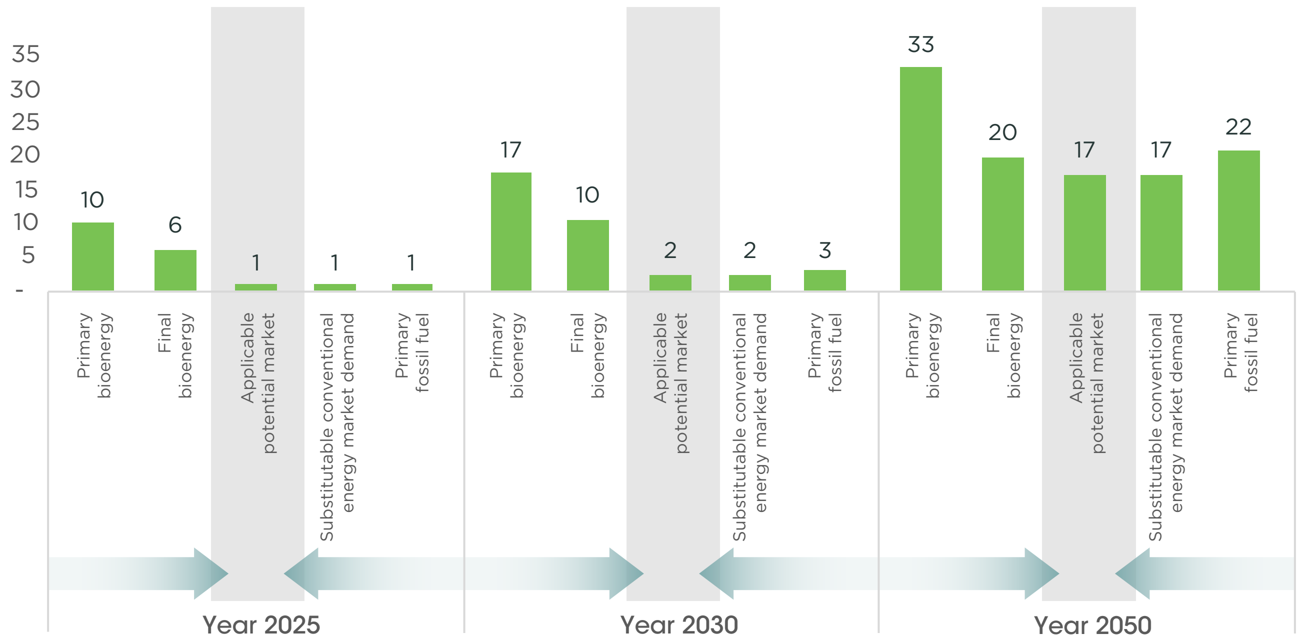
Source: IEA (2020)

Bioenergy pathways and substitutable markets identified in Myanmar

The consideration of both supply and demand in Myanmar's energy mix results in the identification of woody waste as a biomass feedstock for direct combustion in industrial heat generation as the most probable bioenergy application.

Substitutable markets for biomass have been estimated for 2025 (short term), 2030 (medium term) and 2050 (long term). From the basis of bioenergy supply and demand outlined in this study, a prospective bioenergy pathway has been mapped through several of the most probable applications of biomass as a fuel source in Myanmar's energy mix.

FIGURE 59: Bioenergy pathway for Myanmar (2025, 2030 and 2050) in PJ



The total applicable potential market in Myanmar is estimated to be around 0.5 PJ in 2025, 2.2 PJ in 2030, and 17 PJ in 2050.

Bioenergy pathway 1 (direct combustion for industrial heat generation): focuses on replacement of coal with biomass in industry. In Myanmar, solid biomass is the main renewable energy source for industrial processes and is used as much as coal. Coal is mostly consumed in the production of iron and steel as well as non-metallic minerals. In 2017, the total amount of brown coal consumed in the industry sector was approximately 9.3 PJ (IEA, 2017). This pathway aims to substitute the remaining coal demand with solid biomass in heat generation. However, as the application of biomass in steel-making processes is not yet readily available and may be technically restricted, it is considered only for the long-term horizon.

This study assumes that the biomass can be used for co-firing with coal to produce heat in the short term and that 5% of the coal can be replaced by 2025 with biomass in a retrofitted co-firing boiler during the initial pilot phase. By 2030, the co-firing ratio increases to 15%, which is in line with a feasible and economic co-firing ratio.

The cost of retrofitting will rise when the cofiring ratio exceeds 20%. Therefore, in the long term, we assume standalone biomass boilers will be deployed over time until 2050, which will unlock further potential biomass utilisation and increase the replacement ratio to 75%.

The substitutable market is evaluated at 0.5 PJ, 2.2 PJ and 17 PJ by 2025, 2030 and 2050, respectively.

Economic assessment

Since only one bioenergy pathway is analysed in Step 1 for Myanmar in this study, this pathway (direct combustion for industrial heat generation) is compared with its substitutable market using brown coal as energy source in order to determine how much economic value bioenergy can replace. A summary of findings from our bioenergy economics analysis is presented in the following dashboard and summary table:

FIGURE 60: Summary dashboard for bioenergy pathway 1 in Myanmar, 2050

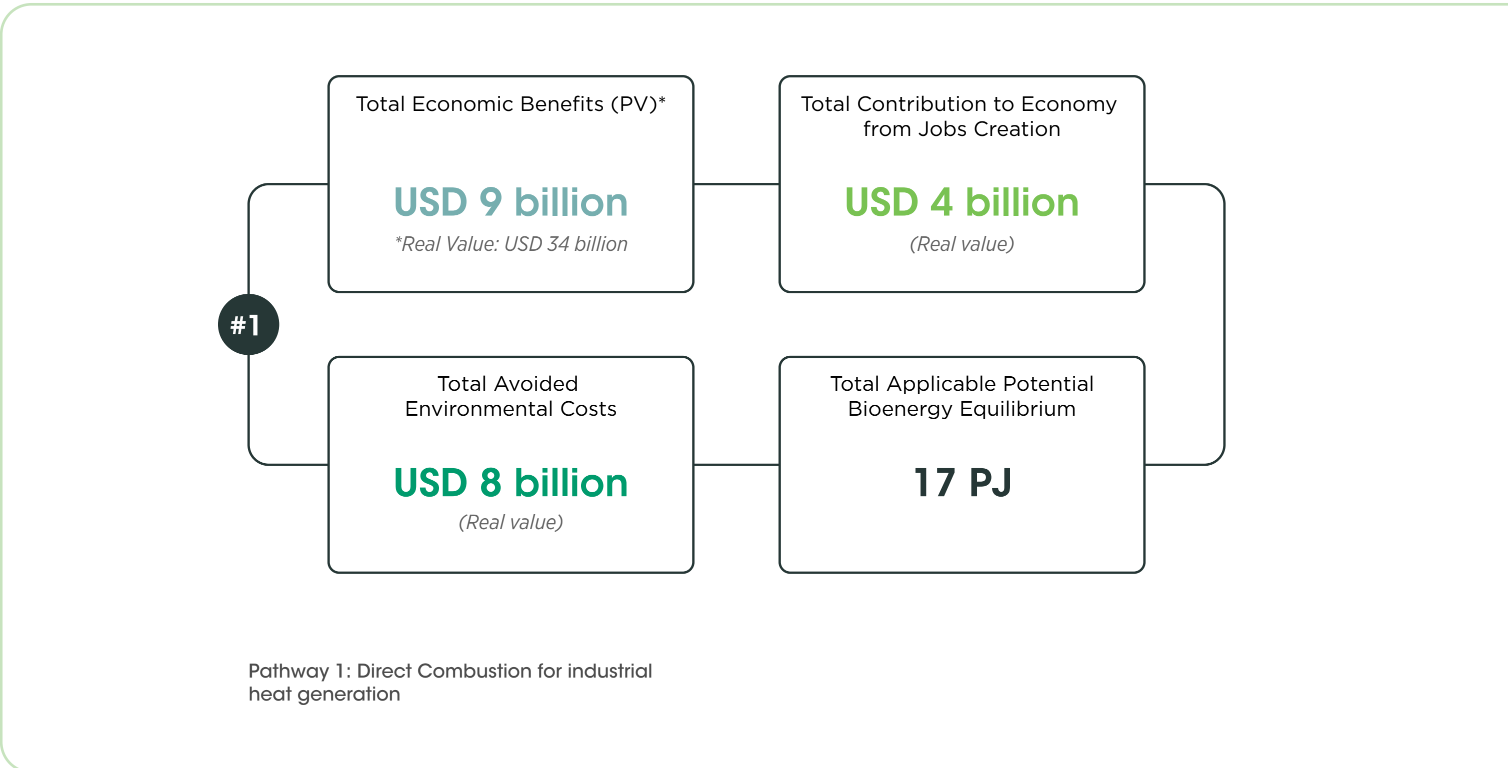


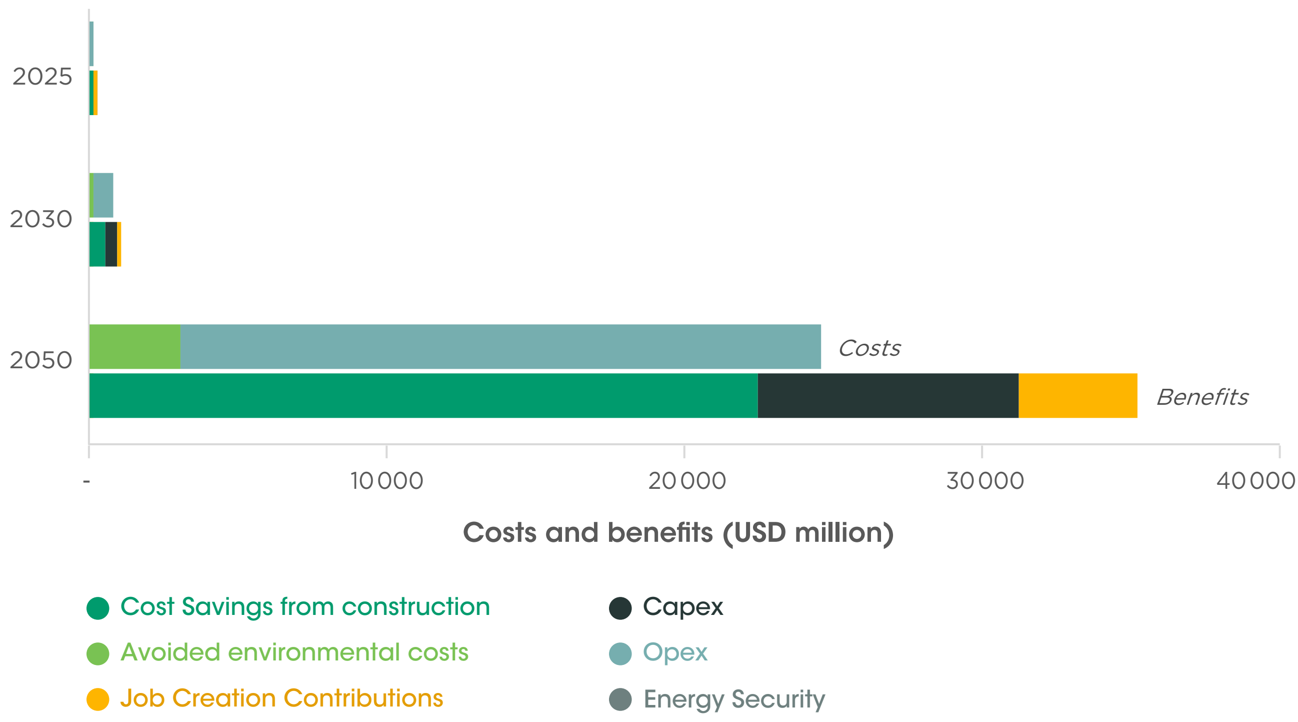
TABLE 42: Summary of findings for bioenergy pathway 1, Myanmar

Type of feedstock	Type of process	Total applicable potential bioenergy equilibrium (2050)		BCR (2050)	Total net present value of economics benefits (NPV) in USD bn (2050)
Woody residues	Direct combustion for industrial heat generation	17.2	PJ	1.30	2.1

This pathway results in a BCR above 1 and provides the economy of Myanmar with approximately USD 2.1 billion in NPV of socio-economic benefits in 2050, creating around 61 000 new resilient jobs and saving around 1.1 million tonnes of GHG emissions per year.

The socio-economic costs and benefits are evaluated in real value (USD million) for 2025, 2030 and 2050, adjusted for economic inflation.

FIGURE 61: Total cost and breakdown of benefits in Myanmar, in USD million (real value)



The bulk of the socio-economic benefits derived from this pathway stem from:

- cost savings from construction;
- avoided CO_2 emissions savings;
- benefits from resilient employment; and
- improvement of energy security.

Socio-economic benefits

I. COST SAVINGS FROM CONSTRUCTION

Cost savings from construction includes an evaluation of the MWe avoided from the costs of constructing and operating traditional fossil fuel plants.

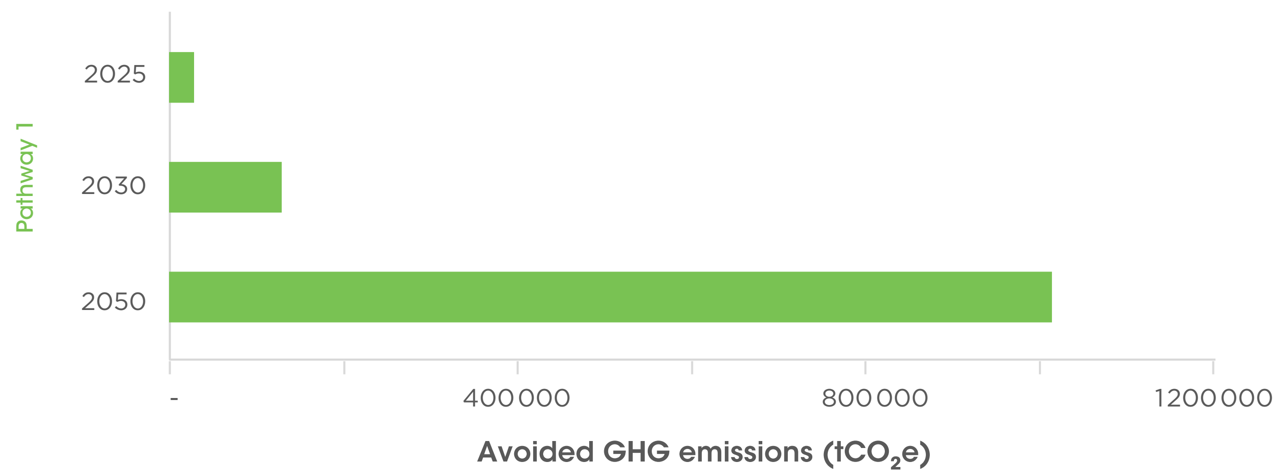
TABLE 43: Estimated capacity of traditional fossil fuel plant saved (MWe), Myanmar

Capacity of traditional fossil fuel plant saved	2025	2030	2050
Capacity of industrial heating facilities saved (MWe)	18.2	87.2	682.8

II. AVOIDED GHG EMISSION SAVINGS

Further socio-economic benefits can be depicted through avoided GHG emission savings by comparing biomass energy plants with traditional fossil fuel energy plants. The potential GHG emissions avoided for bioenergy pathway 1 amount to approximately 1.1 million tCO_2e, as presented below.

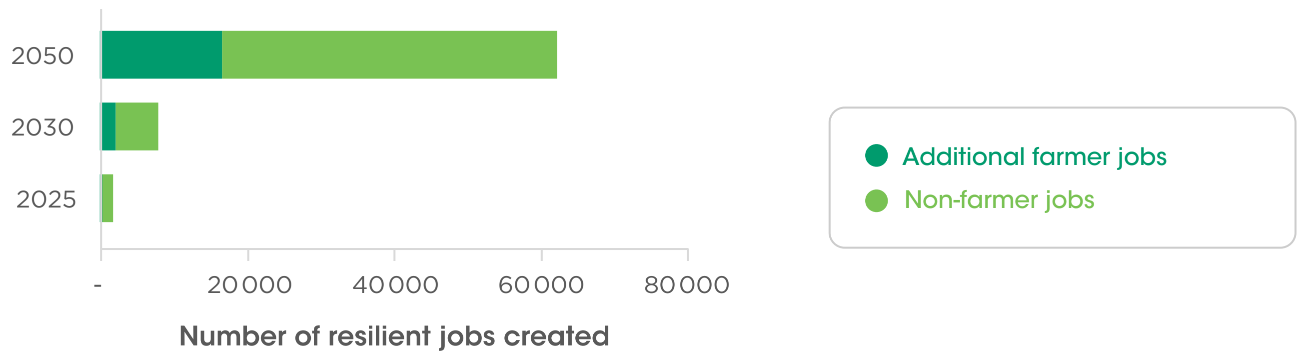
FIGURE 62: Estimated GHG emissions avoided in Myanmar (tCO_2e)



III. BENEFITS FROM RESILIENT EMPLOYMENT (NET JOB BENEFITS28)

By 2050, the implementation of this bioenergy pathway will provide resilient farming and non-farming jobs to approximately 61 000 people, as summarised below.

FIGURE 63: Estimated number of resilient jobs created in Myanmar



IV. IMPROVEMENTS IN ENERGY SECURITY

The table below summarises the improvements in energy security realised through the implementation of the bioenergy pathway. It considers the decrease in reliance on fossil fuel imports and related GDP impacts.

TABLE 44: Percentage of coal imports saved (GWe), Myanmar

	2025	2030	2050
Percentage of coal import saved	2%	8%	21%

As with the other countries examined in this study, the implementation of bioenergy projects will also help countries mitigate the risk of energy supply shortages and cost variations.

Summary of findings

The average annual cost required to realise the bioenergy pathway is estimated to be around USD 240 million through 2050, including capital expenditure, operations and maintenance costs. The average annual socio-economic benefits achieved through the implementation of the pathway would exceed average annual economic costs by USD 70 million through 2050, resulting in net positive gains. The consequent total socio-economic benefits for the bioenergy pathway are presented in ENPV and calculated as a BCR.

28 Benefits are calculated as net job benefits, meaning the figure accounts for lost jobs in the coal, oil and gas industries.

TABLE 45: Socio-economic outcomes arising for potential bioenergy pathways in 2050

Bioenergy pathways	Present value of total socio-economic costs for each bioenergy pathway (in USD million)			Economic net present value of total socio-economic benefits for each bioenergy pathway (in USD million)			Benefit-cost ratio for each bioenergy pathway		
	2025	2030	2050	2025	2030	2050	2025	2030	2050
Bioenergy pathway 1 direct combustion for industrial heat generation	27	173	7 156	6	36	2 091	1.21	1.21	1.30

The key observations from this assessment are as follows:

- The BCR for this bioenergy pathway is greater than 1.0; it would deliver strong ENPV of socio-economic benefits to Myanmar, amounting to USD 2.1 billion of net benefits in 2050.
- The bioenergy pathway shows significant increases in ENPV over the short-, medium- and long-term horizons as bioenergy production methodologies become more efficient and commercially viable.
- The increasing ENPV and positive BCR provide an idea of the socio-economic benefits that could be unlocked through the implementation of this pathway, which merits being prioritised to more quickly lock-in associated benefits based purely on the socio-economic cost–benefit assessment.

Key barriers and interventions

Using political, economic, social, environmental, technological, legal and financial (PESTEL&F) parameters, this study identifies key barriers to implementing the bioenergy pathway and the potential intervening actions required to mitigate these barriers and unlock potential socio-economic benefits.

Key barrier 1: Lack of preferential regulatory framework for bioenergy transition

- Myanmar has an immature legal and regulatory framework for renewable energy, including bioenergy.
- Energy transition policies lack a co-ordinated approach.
- While universal access to electricity will be the priority in the energy policy agenda of Myanmar, the country should take a holistic approach to modernising its energy system based on renewables, phasing-out traditional uses of wood fuels through rural electrification, and halting deforestation and forest degradation by mitigating the pressure on forest resource exploitation and improving the efficiency of woody biomass utilisation.
- The development of a long-term bioenergy transition masterplan will assist the government in focusing its efforts/policies/legal declarations.

4. CONCLUSIONS

To achieve sustainable development and climate management commitments, bioenergy must become a mainstream primary energy source for countries in Southeast Asia.

Fossil fuel consumption in Southeast Asia must be scaled down to the absolute minimum, whilst alternative sources of renewable energy such as bioenergy need to be thoroughly explored and implemented if ASEAN member countries are to reach their climate objectives.

Utilisation of biomass feedstock as a primary energy source has significant potential for growth in the countries of Southeast Asia, thanks to their abundant natural resources and large agricultural sectors; however, deploying biomass feedstock requires changes to bioenergy policies. The key challenges for the countries of the region include: developing a clear understanding of biomass potentials; setting ambitious yet viable targets for bioenergy; integrating bioenergy in national energy policies; and fostering robust biomass industries with clear, time-bound roadmaps.

Using a market economics-based approach, this study applied a 3-step process to first identify and map out bioenergy pathways, analyse ENPV and the relative economic costs and benefits of proposed bioenergy pathways, and then identify barriers impeding their implementation.

Mainstreaming bioenergy in the ASEAN region will require clear bioenergy pathways that illustrate how demand and supply dynamics can drive market growth

The identification of the most promising biomass pathways in each of the countries studied was based on both supply (push) and demand (pull) constraints. The intention was to identify biomass feedstocks with high potential for scalability – as well as the subsequent conversion technologies and end use applications – that can compete with conventional fossil fuel-based products.

All of the pathways identified are summarised in the table below, along with conversion pathways and potential end-uses:

TABLE 46: Identified feedstocks, conversion processes and end-uses for all bioenergy pathways

	#	Type of feedstock	Type of process
Indonesia	1	Agricultural residues from major crops, rubber and acacia	Direct combustion for industrial heat generation
	2		Direct combustion for combined heat and power generation
	3	Palm oil mill effluent (POME) and cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants
Thailand	4	Agricultural residues from major crops, rubber and teak	Direct combustion for industrial heat generation
	5		Direct combustion for combined heat and power generation
	6	Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants
	7	Sugarcane molasses and cassava roots and starch to bioethanol	Fermentation & blending to produce bioethanol
Vietnam	8	Agricultural residues from major crops, rubber and eucalyptus	Direct combustion for industrial heat generation
	9		Direct combustion for combined heat and power generation
	10	Cassava pulp	Anaerobic digestion to generate biogas for both heat boilers and CHP plants
	11	Sugarcane molasses to bioethanol	Fermentation & blending to produce bioethanol
Malaysia	12	Acacia and rubber	Direct combustion for combined heat and power generation
Myanmar	13	Woody residues	Direct combustion for industrial heat generation

Bioenergy provides broader socio-economic benefits that merit interventions by ASEAN governments to create and stimulate markets that will deliver bioenergy transformations.

Each of the bioenergy pathways were reviewed through a high-level socio-economic cost–benefit utilising ENPV and BCR as two key economic parameters. The potential socio-economic benefits for the countries studied include:[29]

29 The socio-economic benefits stated here assume that all bioenergy pathways identified in this study are fully implemented.

- **Indonesia:** approximately USD 91.5 billion of net present value of socio-economic benefits in 2050, creating over 212 000 new resilient jobs and saving around 274 million tCO_2e of GHG emissions per year.
- **Thailand:** approximately USD 26 billion of net present value of socio-economic benefits in 2050, creating over 116 000 new resilient jobs and saving around 102 million tCO_2e of GHG emissions per year.
- **Vietnam:** approximately USD 18.5 billion of net present value of socio-economic benefits in 2050, creating over 50 800 new resilient jobs and saving around 43 million tCO_2e of GHG emissions per year.
- **Malaysia:** approximately USD 6.2 billion of net present value of socio-economic benefits in 2050, creating over 12 600 new resilient jobs and saving around 22 million tCO_2e of GHG emissions per year.
- **Myanmar:** approximately USD 2.1 billion of net present value of socio-economic benefits in 2050, creating over 61 000 new resilient jobs and saving around 1.1 million tCO_2e of GHG emissions per year.

Once socio-economic benefits for each bioenergy pathway were identified, key barriers and interventions were presented. Most of the challenges and interventions identified by this study cut across all the pathways, while there are some challenges that are specific to individual pathways.

TABLE 47: Common challenges and interventions for all pathways

Challenge/intervention	Description
Legal and regulatory enforcement is required to trigger the rapid transformation that ASEAN states require to achieve sustainable development and climate management undertakings	• Strong policy goals and regulatory incentives or enforcement will attract both domestic and foreign investors and players to participate in developing bioenergy projects. • Legal and regulatory changes need to be carefully designed to send the right signal to investors and business leaders so that enabling environments for the development of sustainable bioenergy projects can be created.
The private sector will innovate and invest where there are commercially viable returns	• The commercial viability of bioenergy projects would need to be improved by executing research, development and demonstration to overcome technical barriers and reinforce cost competitiveness against substitutable markets. • Technical hurdles still exist for biomass to be deployed as substitutes for fossil fuels at higher blending rates against coal in steam turbine CHP plants or cement kilns. • Higher blending rates of biofuels against fossil fuels would also need to be explored to move away from fossil fuel consumption. • The private sector will play an expanded role in the market uptake of innovative bioenergy projects. • Given that the mobilisation of financial resources would be key to achieving success in this scale-up process, bioenergy projects would need to capitalise on a massive shift in the allocation of financial capital toward the low-carbon economy, including climate bond, ESG investment, institutional investment and other green finances.

Bioenergy pathways have the potential to deliver strong socio-economic benefits. While delivering these benefits, social and environmental issues need to become mainstream considerations in developing pathways, legal frameworks and markets.

The benefits and risks of bioenergy must be understood in a well-balanced manner and sustainability assurance must be provided in order to attract more investment and boost consumer confidence. It goes without saying that bioenergy production at the expense of the environment should be avoided. While certification schemes are recognised as the most reliable tool to assure the sustainability of biomass production globally, the adoption of third-party sustainability certification schemes for biomass industries using locally produced feedstock for local consumption in Southeast Asia remains sluggish. However, there is a tendency for global business-to-consumer companies involved in biomass and serving domestic consumers in Southeast Asia to seek sustainability assurances. While certain types of biomass energy carriers such as wood pellets and palm oil are currently widely exported from Southeast Asia to global markets with exposure to more stringent sustainability criteria, bioenergy supply chains may need to be tailored to the needs of Southeast Asian markets in the longer term as domestic demand for energy grows. Accordingly, a sustainability assurance system would need to be internalised to raise the credibility of bioenergy projects.

The first step would be to expand the uptake of certification schemes by local biomass producers. For example, in the case of bioenergy conversion to industrial process heat or CHP generation, pre-treated pellets made from agricultural residues and woody biomass must meet both sustainability criteria under the certification schemes and quality assurance standards in accordance with ISO 17225 (quality specification for solid biofuels).

Second, sustainability should be evaluated at the landscape level, based on the mosaic of land-use patterns. Whereas good management practice executed for a small proportion of the landscape does not guarantee overall sustainability, a landscape-based approach for a more comprehensive sustainability governance system should be further explored.

Third, given that land use change is often cited as the critical factor in environmental degradation, proper land use management to regulate, monitor and track land use conversion must be put in place. Legally accepted land conversions that have been subjected to official approval should be accounted for in a transparent manner.

Fourth, since the bioenergy pathways identified in this study look to agricultural residues as feedstocks, residue-based bioenergy systems should be integrated into sustainability governance. For example, the means for biomass pellets made from OPT, or biogas extracted from POME, to be certified under palm oil certification schemes must be defined.

Finally, when assessing sustainability, the positive effects of using bioenergy should also be fully considered and documented. For instance, where market values for agricultural residues are created, farmers can be incentivised to adopt good management practices to increase agricultural yields per unit of land, thus enhancing rather than hampering food production. When farmers are given an economically viable option to treat waste such as POME as feedstock for bioenergy, it can not only provide clean energy but also improve waste management. When energy crops are cultivated on degraded land, bioenergy can provide a practical means of land restoration with positive effects on biodiversity and soil fertility.

Next steps

- At country level, further analysis is required in the following areas:
    a) For each country, a detailed assessment of feedstock at major sites must be conducted, and the quantity and quality of potential feedstock from these sites analysed. In addition, logistical readiness should be assessed to understand real challenges on a case-by-case basis.
    b) Detailed, country-specific action plans must be developed for the short, medium and long terms.
    c) Wider stakeholder engagement is required to identify specific opportunities and challenges in each country.
    d) A standard contract template, such as long term off-taker agreement, should be developed.
    e) Pilot projects should be designed and developed, and the analysis and lessons learnt from such projects shared with other countries.

- At the regional level, a centre focused on enhancing bioenergy utilisation (such as the Regional Centre for Renewable Energy and Energy Efficiency in the Arab region, Bioenergy Europe, etc.) can be established to tackle common challenges faced by all countries. Such an entity could:
    a) create a research and development plan for bioenergy projects and provide technical assistance;
    b) develop regional standards for quality of biomass as feedstock and create a socio-economic evaluation framework for small and large bioenergy projects;
    c) act as an aggregator for small bioenergy projects and manage the potential feedstock from the region systematically;
    d) provide advisory services for project developers to improve access to financing available in the region;
    e) explore a clustering approach to identify the best biomass distribution system, like Malaysia's BioHub development in Sarawak;
    f) collect industry best practices and establish a platform for regional governments to exchange lessons learnt; and
    g) co-ordinate among countries to optimise the use and distribution of biomass at the regional level, taking advantage of its nature as tradable energy carrier.

REFERENCES

ACE (2015a), *ASEAN Plan of Action for Energy Cooperation (APAEC) 2016–2025*, ASEAN Centre for Energy, Jakarta.

ACE (2015b), *ASEAN Energy Outlook*, ASEAN Centre for Energy, Jakarta.

ADB (2009), *Status and Potential for the Development of Biofuels and Rural Renewable Energy: Thailand*, Asian Development Bank, Manila.

Alam, S., A.C. Er and H. Begum (2015), "Malaysian oil palm industry: Prospect and problem", *Journal of Food Agriculture and Environment*, Vol. 1313, No. 12, pp. 143–148.

Alamsyah, R., N.C. Siregar and F. Hasanah (2017), "Torrefaction study for energy upgrading on Indonesian biomass as low emission solid fuel", *IOP Conference Series: Earth and Environmental Science*, Jakarta.

Aqualimpia (2020), Covered Lagoon Digester, https://www.en-aqualimpia.com/why-aqualimpia/, (accessed 20 December, 2021)

ASEAN (2018), "ASEAN, UN move forward in achieving vision 2025 and SDGs", Association of Southeast Asian Nations, www.aseanthai.net/English/ewt_news.php?nid=2618&filename=index2017, (accessed 10 December, 2020).

Azman, N.H. (2020), "BioHub port to spur Sarawak's economy", *The Malaysian Reserve*, https://themalaysianreserve.com/2020/08/27/biohub-port-to-spur-sarawaks-economy/, (accessed 20 September, 2020).

Berndes, G. et al. (2013), "Bioenergy and land use change—state of the art", *WIREs: Energy and Environment*, Vol. 2, No. 3, pp. 282–303.

Biofuels International (2018), "Vietnam biofuel consumption soars", Biofuels International News, https://biofuels-news.com/news/vietnam-biofuel-consumption-soars, (accessed 9 October, 2020).

Christina, B. (2019), "Indonesia launches B30 biodiesel to cut costs, boost palm oil", Reuters, www.reuters.com/article/us-indonesia-biodiesel-idUSKBN1YR0D2, (accessed 10 October, 2020).

Climate Transparency (2019), "Brown to green – the g20 transition towards a net-zero emissions economy", *Climate Transparency*, Vol. 53, No. 9, pp. 1689–1699, www.climate-transparency.org/g20-climate-performance/g20report2019.

Cuong, T.T. et al. (2021), "Renewable energy from biomass surplus resource: potential of power generation from rice straw in Vietnam", *Scientific Reports*, Vol. 11, No. 1, pp. 1–11, Nature Publishing Group UK, https://doi.org/10.1038/s41598-020-80678-3.

Darmawan, S. (2016), "An investigation of age and yield of fresh fruit", *IOP Conference Series: Earth and Environmental Science,* pp. 1–8, Jakarta.

DSM (2020), "Department of Statistics Malaysia: Agriculture", www.dosm.gov.my/v1/index.php?r=column/ctwoByCat&parent_id=45&menu_id=Z0VTZGU1UHBUT1VJMFlpaXRRR0xpdz09#:~:text=The agriculture sector contributed 7.1,Product (GDP) in 2019, (accessed 12 November, 2020).

Duong, B.C. (2020), *Sugar Industry Updated Report*, Ho Chi Minh City, www.fpts.com.vn/FileStore2/File/2020/10/13/EN_FPTSSugar_Industry_Update_ReportSep2020_3b5ad4f3.pdf.

EGAT (2009), *Thailand Power Development Plan 2008 – 2021* (Volume 2021), Electricity Generating Authority of Thailand, Bangkok.

Emmerton, M. et al. (2015), *Myanmar Energy Master Plan*, Asian Development Bank, Naypyidaw, www.burmalibrary.org/docs22/2015-12-Myanmar_Energy_Master_Plan.pdf.

Eriza, H. (2010), *Role of Agro-Industry Process Technology in the Development of Oil Palm Downstream Industry*, Jakarta.

FAO (UN Food and Agriculture Organization) (2020a), "Indonesia country profile", www.fao.org/countryprofiles/index/en/?iso3=IDN, (accessed 15 November, 2021).

FAO (2020b), "Thailand country profile", www.fao.org/countryprofiles/index/en/?iso3=THA, (accessed 22 November, 2020).

FAO (2020c), "Vietnam country profile".

FAO. (2020d), *Malaysia Country Summary*, Rome.

FAO (2020e), *Global Forest Resources Assessment 2020*, Rome.

FAO (2020f), *The State of the World's Forests 2020*, *State of the World*, Rome, https://doi.org/10.1515/9783035608632-002.

FAOSTAT (2021), "FAOSTAT database", www.fao.org/faostat/en/#data, (accessed 29 April, 2021).

Fick, G. et al. (2014), "Using biomass for pig iron production: a technical, environmental and economical assessment", *Waste and Biomass Valorization*, Vol. 5/1, pp. 43–55.

GAR (2017), "How oil palm is grown", Golden Agri-Resources, https://goldenagri.com.sg/about-gar/ (accessed 28 June, 2020).

Gent, S. et al. (2017), *Theoretical and Applied Aspects of Biomass Torrefaction: For Biofuels and Value-Added Products*, Butterworth-Heinemann, Oxford.

Green Palm Sustainability (2015), "Where is palm oil grown", https://greenpalm.org/about-palm-oil/where-is-palm-oil-grown-2, (accessed 23 October, 2020).

Hardie, M. et al. (2018), "Role of site in the mortality and production of acacia mangium plantations in Indonesia", *Southern Forests: A Journal of Forest Science*, Vol. 80, pp. 37–50.

HCH (Holland Circular Hotspot) (2020), "BioHub port and industrial area development in Sarawak showcase", https://hollandcircularhotspot.nl/events/biohub-port-and-industrial-area-development-in-sarawak-showcase, (accessed 18 September, 2020).

Hiangrat, R. (2019), "Challenges and opportunities for the development bioenergy", *GBEP Bioenergy Week,* pp. 1–15, Thai Sugar Millers Corp. Ltd., Manila.

IEA (International Energy Agency) (2020), "IEA - data and statistics", www.iea.org/data-and-statisticsm, (accessed 22 July, 2020).

IEA (2019), "Southeast Asia energy outlook 2019 – analysis", www.iea.org/reports/southeast-asia-energy-outlook-2019#.

Indonesia Investments (2018), "Rubber (natural)", www.indonesia-investments.com/business/commodities/rubber/item185, (accessed 28 June, 2020).

IRENA (2020a), *Global Renewables Outlook: Energy Transformation 2050*, International Renewable Energy Agency, www.irena.org/publications/2020/Apr/Global-Renewables-Outlook-2020.

IRENA (2020b), *Post-COVID Recovery: An Agenda for Resilience, Development and Equality*, www.irena.org/publications/2020/Jun/Post-COVID-Recovery.

IRENA (2018), *Renewable Energy Market Analysis: Southeast Asia*, https://irena.org/publications/2018/Jan/Renewable-Energy-Market-Analysis-Southeast-Asia.

IRENA (2017a), *Biofuel Potential in Southeast Asia: Raising Food Yields, Reducing Food Waste and Utilising Residues*, www.irena.org/publications/2017/Nov/Biofuel-potential-in-Sub-Saharan-Africa.

IRENA (2017b), *Renewable Energy Prospects: Indonesia*, International Renewable Energy Agency (IRENA), www.irena.org/remap.

Jaganathan, J. (2018), "Indonesia imposes mandatory use of b20 biodiesel in drive to cut fuel bill", Reuters, www.reuters.com/article/us-singapore-siew-indonesia-idUSKCN1N5160, (accessed 14 June, 2020).

Junginger, M., J. Koppejan and C.S. Goh. (2020), "Sustainable bioenergy deployment in East and South East Asia: Notes on recent trends", *Sustainability Science*, Vol. 15, No. 1, pp. 1455–1459.

Kardooni, R., S.B. Yusoff and F.B. Kari (2015), "Barriers to renewable energy development: five fuel policy in Malaysia", *Energy and Environment*, Vol. 26, No. 8, pp. 1353–1361.

Kondalamahanty, A., and P. Raj (2021), "Indonesia's B30 program to drive global biodiesel production in 2021–2030: Report", *S&P Global*, www.spglobal.com/platts/en/market-insights/latest-news/agriculture/070621-indonesias-b30-program-to-drive-global-biodiesel-production-in-2021-2030-report, (accessed 13 August, 2021).

Lim, S.C., K.S. Gan and Y.E. Tan (2004), *Properties of Acacia Mangium Planted in Peninsular Malaysia*, Kuala Lumpur.

Lokman, N.A. et al. (2021), "A brief review on biochemical oxygen demand (BOD) treatment methods for palm oil mill effluents (POME)", *Environmental Technology and Innovation*, Vol. 21, November, pp. 1–29, Elsevier B.V., https://doi.org/10.1016/j.eti.2020.101258.

Malay Mail (2020), "Sarawak biohub port project to kickstart in q1 2021" , https://www.malaymail.com/news/money/2020/08/26/sarawak-biohub-port-project-to-kickstart-in-q1-2021/1897457, (accessed 20 December, 2021).

McKinsey & Company (2018), *Decarbonisation of Industrial Sectors: The Next Frontier*.

Myanmar Times (2015), "Myanmar third-worst for deforestation rate, says un", www.mmtimes.com/national-news/16436-myanmar-third-worst-for-deforestation-rate-says-un.html, (accessed 20 June, 2020).

Netherlands Embassy, Bangkok (2016), *Bioenergy in Thailand*.

OECD (Organisation for Economic Cooperation and Development) (2020a), *Global Energy Review 2020*, Paris, https://doi.org/10.1787/a60abbf2-en.

OECD (2020b), *Agricultural Policy Monitoring and Evaluation 2020*, Paris, https://doi.org/10.1787/928181a8-en.

OECD and FAO (2016), *OECD–FAO Agricultural Outlook 2016–2025*, OECD Publishing, Paris.

Osaka Gas (2017), "Pilot project launched in Thailand to explore biogas refining and vehicle natural gas fuel supply for future commercial usage", www.osakagas.co.jp/en/whatsnew/1266982_11885.html, (accessed 13 August, 2021).

Ozturk, M. et al. (2017), "Biomass and bioenergy: An overview of the development potential in Turkey and Malaysia", *Renewable and Sustainable Energy Reviews*, Vol. 79, pp. 1285–1302, Pergamon, https://doi.org/10.1016/J.RSER.2017.05.111.

Papong, S. et al. (2004), *Overview of Biomass Utilisation in Thailand*, Bangkok.

Philip, E. et al. (2020), *Third Biennial Update Report To the UNFCC*, Kuala Lumpur, https://unfccc.int/sites/default/files/resource/MALAYSIA_BUR3-UNFCCC_Submission.pdf.

Pirelli, T., A. Rossi and C. Miller (2018), *Sustainability of Biogas and Cassava-Based Ethanol Value Chains in Viet Nam*, FAO, www.fao.org/documents/card/en/c/I9181EN.

Pramono, A.A. et al. (2011), *Managing Smallholder Teak Plantations: Field Guide for Farmers*, *Managing smallholder teak plantations: Field guide for farmers*, CIFOR, Jakarta, https://doi.org/10.17528/cifor/003493.

Prasertsri, P., M. Hanikornpradit and E. Mullis (2020), *Biofuels Annual Report: Thailand*, Bangkok.

PT SBI (PT. Sumber Bakat Insani) (2018), *PT Semen Indonesia Tbk Sustainability Report*, Indonesia.

Reuters (2020a), "Indonesia looks at policy revamp to keep biodiesel programme alive", www.businesstimes.com.sg/energy-commodities/indonesia-looks-at-policy-revamp-to-keep-biodiesel-programme-alive, (accessed 15 January, 2021).

Reuters (2020b), "Crude oil prices slump amid coronavirus chaos", https://energy.economictimes.indiatimes.com/news/oil-and-gas/crude-oil-prices-slump-amid-coronavirus-chaos/74766516, (accessed 15 January, 2021).

Reuters (2019), "Thailand aims to reduce rubber plantations, ramp up value of exports title", www.reuters.com/article/thailand-rubber/thailand-aims-to-reduce-rubber-plantations-ramp-up-value-of-exports-idUKL4N28E2EW, (accessed 18 June, 2020).

Richard, T. (2010), "Challenges in scaling up biofuels infrastructure", *Science*, Vol. 329, No. 5993, pp. 793–796.

Ritchie, H. and M. Roser (2018), "Thailand: CO_2 country profile", *Our World in Data*, https://ourworldindata.org/co2/country/thailand, (accessed 10 December, 2021).

RSB (Roundtable on Sustainable Biomaterials) (2016), *Principles & Criteria for the Sustainable Production of Biomass, Biofuels and Biomaterials*, Geneva.

Russell, T.H. and P. Frymier (2012), "Bioethanol production in Thailand: A teaching case study comparing cassava and sugarcane molasses", *The Journal of Sustainability Education*, www.susted.com/wordpress/content/bioethanol-production-in-thailand-a-teaching-case-study-comparing-cassava-and-sugar-cane-molasses_2012_03, (accessed 20 September, 2020).

S&P Global (2014), "Thai consumption of E20, E85 increases with more E85 cars, gas stations", www.spglobal.com/platts/en/market-insights/latest-news/agriculture/082214-thai-consumption-of-e20-e85-increases-with-more-e85-cars-gas-stations, (accessed 10 September, 2020).

Salleh, S.F. et al. (2020), "Transitioning to a sustainable development framework for bioenergy in Malaysia: Policy suggestions to catalyse the utilisation of palm oil mill residues", *Energy, Sustainability and Society*, Vol. 10, No. 1, pp. 1–20, Springer Berlin Heidelberg, https://doi.org/10.1186/s13705-020-00269-y.

Setboonsarng, C. and P. Wongcha-um (2018), "Thailand's biggest wind power generator plans solar, hydro expansion", *Reuters*, www.reuters.com/article/us-thailand-windpower/thailands-biggest-wind-power-generator-plans-solar-hydro-expansion-idUSKBN1FP0CZ, (accessed 12 November, 2021).

Shafiq, M., U. Rehman and R. Santella (2020), *Thailand: Sugar Annual Report Highlights 2020*, Bangkok.

Souza, G.M. et al. (2017), "The role of bioenergy in a climate-changing world", *Environmental Development*, Vol. 23, pp. 57–64, Elsevier, https://doi.org/10.1016/J.ENVDEV.2017.02.008.

Sovacool, B.K. (2013), "Confronting energy poverty behind the bamboo curtain: A review of challenges and solutions for Myanmar (Burma)", *Energy for Sustainable Development*, Vol. 17, No. 4, pp. 305–314.

Sriroth, K., R. Chollakup and S. Chotineeranat (2000), "Processing cassava waste for improved biomass utilisation", *Biosource Technology*, Vol. 71, No. 1, pp. 63–69.

Sumantakul, V. (2008), *Teak Resources in Thailand*, Rome.

Thai Tapioca Starch Association (2016), "Tapioca production", http://thaitapiocastarch.org/en/information/statistics/tapioca_production, (accessed 20 November, 2020).

The Star (2011), "Malaysia is king of wood products export", available from *Eco-Business News*, www.eco-business.com/news/malaysia-is-king-of-wood-products-export/, (accessed 9 August, 2020).

Trinh, T.A. and T.P. Linh Le (2018), "Biofuels potential for transportation fuels in Vietnam: A status quo and SWOT analysis", *IOP Conference Series: Earth and Environmental Science*, Vol. 143, No. 1, pp. 1–19, https://doi.org/10.1088/1755-1315/143/1/012065.

Triwiyono, B. (2015), *The Current Situation of Cassava Processing in Indonesia,* Jakarta.

Tun, M.M. et al. (2019), "Biomass energy: An overview of biomass sources, energy potential, and management in Southeast Asian countries", *Resources*, Vol. 8, No. 2, pp. 1–19, https://doi.org/10.3390/resources8020081.

Tun, M.M. and D. Juchelková (2019), "Biomass sources and energy potential for energy sector in Myanmar: An outlook", *Resources*, Vol. 8, No. 2, pp. 1–19, https://doi.org/10.3390/resources8020102.

USDA (US Department of Agriculture) (2020), *Vietnam Ethanol Background Report*, Ho Chi Minh City.

Utilitas (2017), "About biohubs", https://utilitas.com.au/portfolio-item/about-biohubs/, (accessed 18 August, 2020).

Walker, S. et al. (2018), "Compilation of best management practices to reduce total emissions from palm oil production", *Roundtable on Sustainable Palm Oil*, November, pp. 1–157.

Wattana, S. (2014), "Bioenergy development in Thailand: Challenges and strategies", *Energy Procedia*, Vol. 52, pp. 506–515, Elsevier, https://doi.org/10.1016/J.EGYPRO.2014.07.104.

WBG (World Bank Group) (2021), "The world bank group database".

WEPA (Water Environment Partnership in Asia) (2020), "Industrial effluent standard in Thailand", (accessed 19 November, 2021).

Yusof, A. (2019), "Malaysia's timber and timber-related exports to record rm23b in 2019", *New Straits Times*, www.nst.com.my/business/2019/01/453608/malaysias-timber-and-timber-related-exports-record-rm23b-2019, (accessed 22 August, 2020).

Zafar, S. (2019), "Biomass energy in Vietnam", *Bioenergy Consult*, www.bioenergyconsult.com/biomass-energy-vietnam/#:~:text=Vietnam is one of the,oil equivalent per capita%2Fyear.&text=Vietnam has set a target,to 2%2C000 MW in 2030, (accessed 22 August, 2020).

Zareei, S.A. et al. (2017), "Rice husk as an alternative energy for cement production and its effect on the chemical properties of cement", *Case Studies in Construction Materials*, Vol. 7, No. 1, pp. 73–81.

APPENDICES

Appendix A: Potential of methane extraction from oil palm biomass in Malaysia – detailed analysis

Malaysia has a theoretical potential to extract 17 million tonnes of biomethane (424 million tCO_2e) from palm oil biomass on an annual basis, which is 2.6 times more than Malaysia's total annual GHG emissions. The biomethane potential, with a breakdown of biomass sources, is summarised in the table below.

TABLE 48: Biomethane potential by biomass source

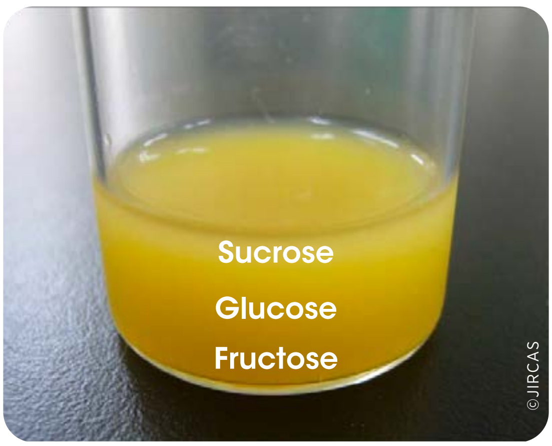
		CH4 potential: million tonnes/year	Million tCO_2e/year
Oil palm trunk (OPT)	Juice	1.2	29
	Fibre	2.7	66
Oil palm frond (OPF)	Juice	1.2	29
	Fibre	8.8	219
Empty fruit bunch (EFB)	Juice	0.3	8
	Fibre	1.9	47
POME		1.0	25
Total potential		**17.0**	**424**

The details of this analysis are presented below.

1. CH_4 POTENTIAL FROM OPT JUICE AND OPT FIBRE

Theoretical potential of CH_4 from OPT juice and OPT fibre can be estimated as follows:

1) Oil palm plantation area (2018) is 5.9 million ha (MPOB, Malaysian Palm Oil Board);
2) of which matured plantation area bearing fruits stands at 5.2 million ha.
3) Given that 4% of the matured area is replanted (Hambali and Rivai, "The Potential of Palm Oil Waste Biomass in Indonesia in 2020 and 2030", https://iopscience.iop.org/article/10.1088/1755-1315/65/1/012050/pdf), the area replanted is estimated to be around 0.21 million ha.
4) Given that 140 are planted per ha, the number of felled OPT is 29.2 millions.
5) Given that each OPT weighs 2 tonnes, the production volume of OPT stands at 58 428 thousand tonnes per year.
6) Given that the water content of OPT is 80%, OPT juice stands at 46 743 thousand tonne.
7) Given that COD ratio to OPT juice is 10%, COD contained in OPT juice amounts to 4 674 thousand tonne-COD/year.
8) Given that methanation occurs at 350 Nm^3/ton-COD, CH_4 potential from OPT juice amounts to 1 634 million Nm^3 or 1.2 million tonnes (1 Nm^3 = 0.717 kg/m^3), which corresponds to 29 million tCO_2e.
9) Given the solid content of OPT (the remaining 20%) comprises 50% cellulose, 35% hemicellulose; 35% and 15% of lignin, OPT fibre (cellulose & hemicellulose) amounts to 9 933 thousand tonne.
10) Given that COD derived from cellulose (converted to glucose) is 1.067 tonne-COD/tonne-glucose and COD derived from hemicellulose (converted to xylose) is 1.067 tonne-COD/tonne-xylose, total COD derived from OPT fibre amounts to 10 598 thousand tonne-COD/year.
11) CH_4 potential from OPT fibre amounts to 3 709 million Nm^3 or 2.7 million tonnes (1 Nm^3 = 0.717 kg/m^3), which corresponds to 66 million tCO_2e.



2. CH_4 POTENTIAL FROM OPF JUICE AND OPF FIBRE

Oil palm frond (OPF) has the largest quantity of carbon stock within a single oil palm tree. It is constantly pruned not only when fresh fruit bunches (FFB) are harvested but also for the maintenance of plantations. OPF also enters the harvest residue stream when oil palm trees have reached the end of their commercial life and are being cut down for replantation.

Each OPF is about two to three meters long, weighs about 10 kg, and has many leaves on both ends of one petiole. After pruning, it is used as a mulching material to cover the roots of oil palm trees. However, there are almost no other practical ways of using OPF.

OPF, like other palm biomass, contains nutrients such as nitrogen, phosphorus and potassium, but they are concentrated to two-thirds from the tip of the leaf to the central part. The remaining part near the base of the petiole is low in nutrients, but rich in sugar and cellulose, so would be more suitable for use as biofuel or biochemical raw materials rather than organic fertiliser.

The quantity of OPF biomass generated annually is estimated to be about 3.3 times that of OPT. Therefore, the production volume of OPF is calculated at 192 814 kt/year (58 428 kt multiplied by 3.3).

Assuming that the water content of OPF has the same level as OPT at 80%, and by using the same formula for estimating the CH_4 potential from OPT, theoretical potential of CH_4 from OPF juice and OPF fibre can be estimated at 1.2 million tonnes (29 million tCO_2e). Note that COD ratio to OPF juice is 3% as opposed to OPT at 10%.

Likewise, CH_4 potential from OPF fibre is estimated to be 8.8 million tonne (219 million tCO_2e).

3. CH4 POTENTIAL FROM EFB JUICE AND EFB FIBRE

FFB production in 2018 in Malaysia was 98 419 thousand tonnes (FAOSTAT, 2021). Based on the mass balance of oil palm (Table 48), EFB generated is calculated at 20 668 thousand tonnes. By applying the same formula with COD ratio to EFB juice at 10%, CH_4 potential from EFB juice is estimated to be 0.3 million tonnes (8 million tCO_2e) whereas CH_4 potential from EFB fibre to be 1.9 million tonne (47 million tCO_2e).

4. CH4 POTENTIAL FROM POME

Based on the mass balance of oil palm (Table 48), POME generated is calculated at 57 083 thousand tonnes. By applying the same formula with COD ratio to POME at 7%, CH_4 potential from POME is estimated to be 1.0 million tonnes (25 million tCO_2e).

Appendix B: Case studies

Case Study 1: Cement production in Indonesia

OVERVIEW OF CASE STUDY

PT Semen Indonesia Tbk (PT SI), a state-owned cement producer and one of the largest cement companies in Indonesia, began a transition to using biomass feedstock as a fuel source for all its plants in 2005 (IDN Financials, 2020). PT SI's goal is to retrofit all their existing cement plants, and construct all of their new cement plants, with the capability of using alternative fuel sources in their manufacturing processes. PT SI stated that their goal is to support the government's aim of reducing Indonesia's reliance on coal (CemNet, 2021), which aligns with the company's mission to focus on sustainable environment preservation.

As of 2021, all PT SI cement factories utilise biomass as an alternative fuel. Solusi Bangun Andalas (Aceh), Semen Padang (West Sumatra) and Semen Tonasa (South Sulawesi) use biomass feedstock coming from rice husks and saw dusts in their manufacturing processes. Additionally, the Tuban Factory in East Java, which operates the Waste Heat Recovery Power Generation (WHRPG) plant, utilises a range of biomass feedstock such as rice husks, cocopeat, tobacco waste, corn kernels and refuse-derived fuel (PT SBI, 2018).

Continuing their commitment to finding alternative fuel sources to facilitate the implementation of economically viable solutions away from traditional fossil fuels, PT SI has also looked beyond biomass feedstock and developed a factory that processes waste into fuel. PT SI, through its subsidiary PT Solusi Bangun Indonesia (PT SBI), will be the first off taker for the TPA Tritih Lor Cilacap Refuse Derived Fuel (RDF) project. The project has been recognised as a leading project in Indonesia for the emissions reduction agenda. The Tritih Lor Cilacap RDF project will supply RDF to one of PT SBI's cement plants in Cilacap, Central Java, which is located close to the Tritih Lor TPA location (2 km away).

This project comprises co-operation between PUPR, KLHK, the Central Java Provincial Government, the Cilacap Regency Government, Bappenas, and the Danish Government to build the project with a purpose to utilise urban waste as non-fossil-based alternative fuel.

TABLE 49: TPA Tritih Lor Cilacap Project data

Project information	Data
Construction year	2017
Target year of operation	2020 (operating now)
Investment value	USD 6.2 million (USD 0.9 million for additional cement processing facilities, USD 2.8 million for RDF facilities)
Waste processing capacity	120 tonnes/day
Land area	1 ha (4/5 of the total area for biodrying)
Final result	40–60 tonnes of RDF
Tipping fee	USD 17/tonne (USD 8.5/tonnes for the first 5 years of operation)

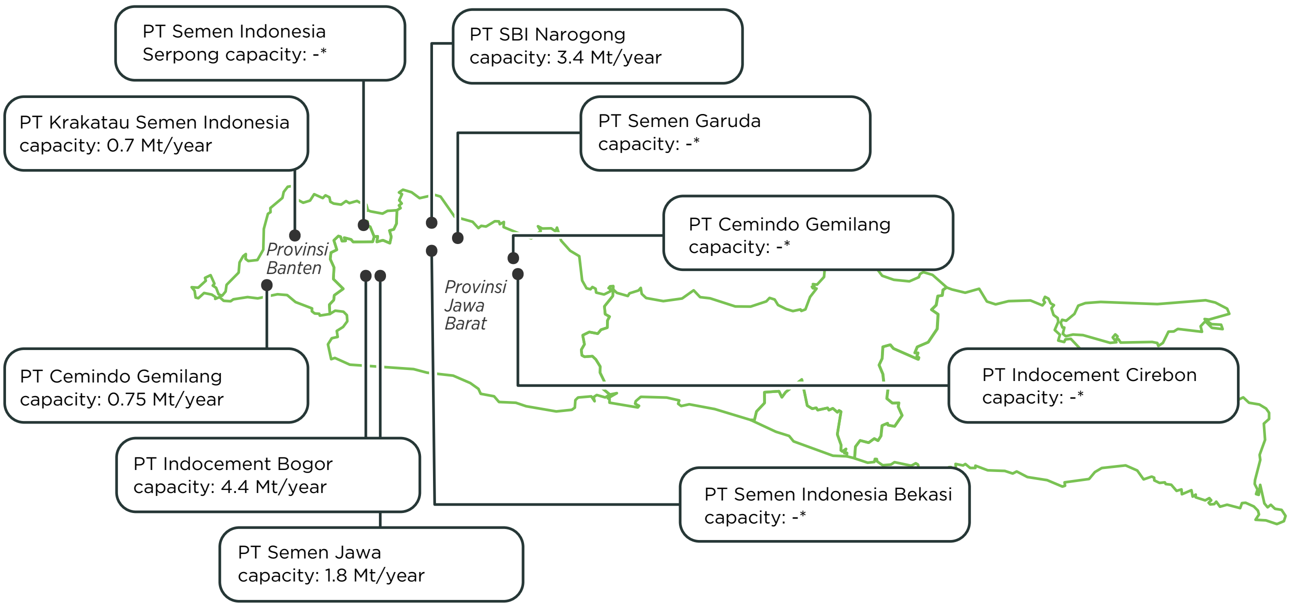
Source: PT SBI (2018)

POTENTIAL MARKET OF BIOENERGY IN THE CEMENT INDUSTRY

The cement industry in Indonesia produces 75 million tonnes of cement per year, consuming 9 million tonnes of coal and emitting a total of 17 million tonnes of CO_2 emissions. Replacing 10% of coal with biomass will save around 1.7 million tonnes of CO_2 emissions.

In order to support emissions reductions in the cement industry, the Government of Indonesia introduced Regulation of the Minister of Industry No. 12/2012 (Permen Perindustrian No. 12/2012) on a roadmap to GHG emission reduction in the cement industry. If the government implements the action plan mentioned, in the long term there is a massive potential for the use of alternative fuel in the cement industry. To date, there are several large cement factories located in Banten and West Java that could potentially become the next off taker for biomass products.

FIGURE 64: Location of cement factories in West Java Province



**There is no information regarding the related factory capacity*

Based on 2018 annual reports of each company.

Disclaimer: Boundaries and names shown on this map do not imply any endorsement or acceptance by IRENA.

Although Indonesia' cement industry has considerable potential for increasing its use of alternative fuels, there are still several factors that need to be considered in marketing bioenergy products:

→ **Political and legal aspects: Indonesia has announced some policies and regulations to promote alternative fuels in the cement industry and more are being planned and drafted. Based on the Regulation of the Minister of Industry no. 12/2012, the government is expected to draft the following provisions:**

- Formulate laws and regulations related to the use of alternative raw materials and alternative fuels in the cement industry.
- Dissemination of laws and regulations related to the use of alternative raw materials and alternative fuels in the cement industry.
- Socialisation of laws and regulations related to the use of alternative raw materials and alternative fuels in the cement industry.

Furthermore, the Ministry of Industry composed a program for emissions reductions for the different industrial sectors as one of its workplans in 2020, in which the energy transition that PT SI have implemented is deemed as a solution for emissions reduction in the cement industry. This is also aligned with the 2015–2035 National Industrial Development Master Plan on renewable energy utilisation.

If the government successfully implements the regulations, the demand for alternative fuel for the cement industry will increase significantly.

→ Political and legal aspects

- The Road Map for Cement Industry GHG Emission Reduction in Indonesia stated that in the 2016–2020 period, the cement industry is required to reduce specific GHG emissions by 3% in aggregate.

→ Economic and technical aspects

- New technology and additional capex will be required to accommodate the use of bioenergy in its operations.
- There is the potential for additional transportation costs from bioenergy products to the cement factory location. To minimise logistics costs, it is preferential that bioenergy is produced close to the cement factory.
- There is a risk that offtake is not secured and the quality of bioenergy products for the cement plant do not meet the quality of bioenergy required as an alternative fuel for coal. To reduce these risks, it is preferential that the cement business participates in biomass fuel supply projects as the project operator/sponsor

LESSONS LEARNT

- Government policy and regulatory incentives are effective measures to promote the development of bioenergy projects. Robust policy and regulatory frameworks should be developed and implemented in a way that incentivises investment in bioenergy projects.
- Research and development are required to ensure that new projects are both technically and financially feasible.
- The sourcing of feedstock at the regional level is preferred to reduce logistic costs to make projects more viable.
- The quality of biomass feedstock needs to be checked and standards need to be designed to minimise the risk of non-compliant feedstocks.

Case Study 2: Financing bioenergy projects in Southeast Asia – interviews with regional investors & banks

Most financiers expressed investment appetite in bioenergy projects and shared several good cases but most are at small scales.

This study conducted market consultations with several energy financiers in the region, including representatives from developers, commercial and development banks, and infrastructure funds. During the consultations, most financiers expressed investment appetite for bioenergy projects. There was reluctance to talk about project-specific details due to confidentiality obligations; however, several good cases were mentioned where biomass was used as the alternative to diesel in transportation or fossil fuels used to generate heat and electricity for industrial usage, such as sugar mills. Most of the cases shared were small-scale projects.

Challenges remain and very few investments have been made.

From the conversations with these financiers, we found there are still very few investments that have been made in bioenergy in this region in the past due to various challenges. One of the most common challenges cited during the consultation was project scale. Conversations with financiers revealed that the scale of projects do not fit investment criteria. One potential solution is to aggregate or cluster small projects together. One example is the Negros Occidental biomass power plants in the Philippines – a portfolio of three Filipino biomass power plants in Negros Occidental converting sugarcane waste into electricity. The three projects are in the municipalities of La Carlota, Manapla and San Carlos. The project reached financial close in 2016 and, by 2019, all projects were connected to the power grid.

TABLE 50: Project details of Negros Occidental biomass plant in the Philippines

Project details of Negros Occidental biomass plant in Philippines	
Capacity	69.9 MW
Feedstock	Sugarcane waste
Technology	Circulating fluidised bed boiler technology
Financial close	2016
Payment mechanism	20-year PPA with a feed-in-tariff of PHP 6.63 (USD 0.15) per kWh
CAPEX	USD 161 million
Lenders	International Finance Corporation (IFC), Clean Technology Fund and Government of Canada

Several other challenges identified are summarised in the table below.

TABLE 51: Key challenges of investing in bioenergy projects

Dimension	Challenges
Political and legal	The current regulatory framework is not attractive to private sector investment.
Economic	There is low security of feedstock supply, and feedstock costs are too high (including collection, logistics, storage and processing). Perceptions are that total project costs are too high to achieve favourable commercial returns.
Technological	More advanced technology is still not commercially proven and there are other challenges around feedstock sourcing, distances between plantation area and energy plants, etc.
Environmental	Assessment of sustainability of the project is challenging due to the different types/sources of the feedstock that can trigger E&S safeguarding concerns.
Financial	Bioenergy projects are too often sub-scale for meeting investment criteria and the market does not yet offer a pipeline of transactions that can create economies of scale.

To tackle these challenges, the following suggestions were proposed during the consultation:

1) Design policies to de-risk investment through tax incentives, credit lines and government grants to attract co-financing.
2) Government support and leadership in developing and overseeing regional bioenergy resources to provide security of supply and ESG compliance.
3) Create industrial clusters to consolidate and aggregate individual small projects to improve access to financial resources whilst optimising biomass supply chains, potentially reducing the cost of feedstock collection as a whole.
4) Develop standardised contracts for small projects (feedstock supply agreement, energy offtake agreement, etc.).
5) Educate and communicate with the local community about the economic, environmental and social benefits of bioenergy projects.

LESSON LEARNT

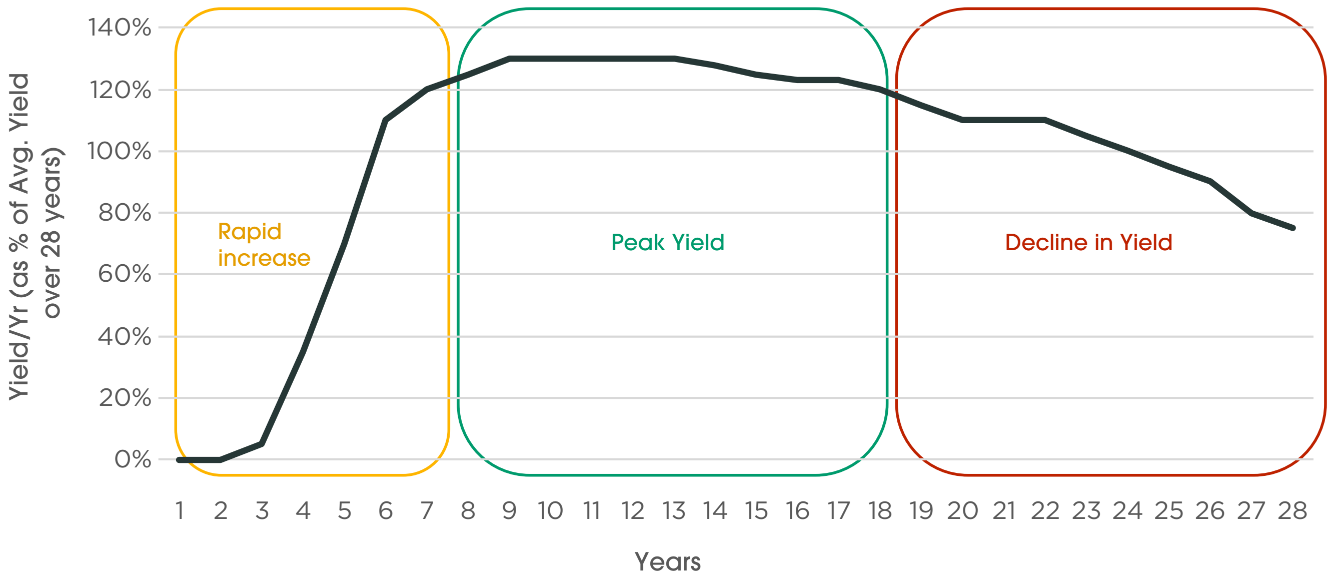
- The current regulatory environment in most countries in ASEAN needs to be improved to attract more private sector investment in bioenergy projects.
- R&D is required to make advanced technologies commercially proven for investors' consideration, resulting in increased yields of biomass feedstock and increased efficiency in the energy conversion process.
- Consolidation and aggregation of small projects as well as bio-industry clustering can not only resolve the scale issues, but also tackle challenges around logistics and feedstock availability.
- A framework to assess the socio-economic benefits of bioenergy projects will help investors to truly understand the sustainability benefits when assessing bioenergy project investments.

Case study 3: Utilisation of palm oil biomass – Malaysia's technology development journey

Introduction

Oil palm trees are periodically cut down and replaced every 20–25 years due to declining yield of fruits in aged trees. Commonly, oil palm trees have an economical life span of up to 25 years (Darmawan, 2016) and begin bearing fruit at about 2–3 years (GAR, 2017), with production reaching a peak between years 9 and 18 (Alam, Er and Begum, 2015). The approximate yield of an oil palm tree over its useful life is presented in the figure below:

FIGURE 65: Oil palm age and yield profile

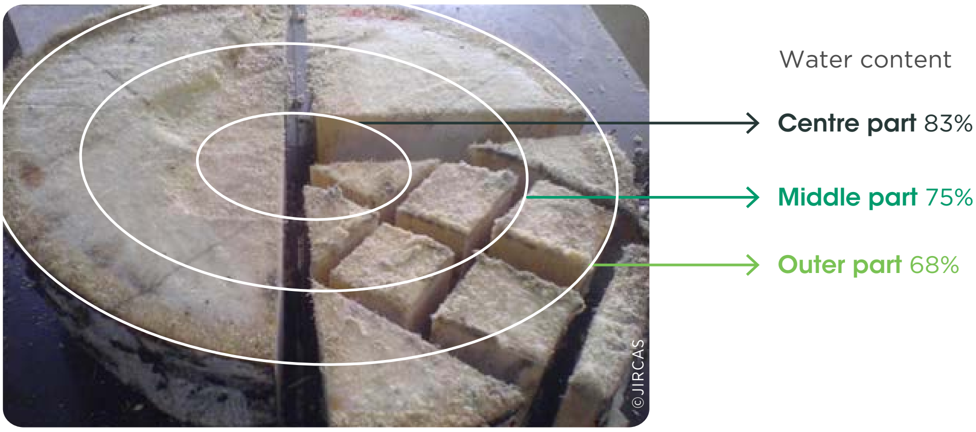


Source: Alam, Er and Begum (2015)

Malaysia and Indonesia produce an estimated 65 million tonnes of oil palm trees annually. An oil palm tree has a water content of 70% or more, where the liquid contained within oil palm trees is a sugar solution containing large amounts of glucose, sucrose and fructose. While conversion to bioethanol and sugar purification have been studied as a possible way of using the sugar solution contained in oil palm trees, the effective method of utilisation has not been established due to the high treatment cost of such a high-concentration waste liquid.

The remaining 30% of the oil palm tree is solid and is rich in cellulose and starch, but the density of the dried tree is about 0.35 g/cm^3, on average, making it inefficient to transport. Although the use of felled OPT (by processing it into pellets) has been explored, it has been found to be unsuitable for biofuel feedstock without further processing due to the large amount of low melting point ash contained.

For this reason, most of the felled OPTs are just left on the plantations as waste without being utilised. As a result, the sugar solution easily spoils, causing not only foul odours and water pollution but also a source of greenhouse gases such as N_2O and CH_4, which have a high greenhouse effect. Rotting OPTs can accelerate the spread of disease in plantations by providing a breeding ground for pests and pathogens, which reduces palm oil production efficiency. In addition, felled areas filled with OPTs on the ground tend to deter farmers from replanting and encourage them to encroach on adjacent forests for new palm plantations.



Sustainable replantation of oil palm

OVERVIEW

To address these issues, a project for the sustainable replantation of oil palm by adding value to oil palm trunk through scientific and technological innovation has been carried out by the Japan International Research Center for Agricultural Sciences (JIRCAS) in co-operation with the Malaysian Palm Oil Board, Malaysia University of Science and Technology, Forest Research Institute Malaysia, IHI Corporation and other stakeholders since 2019.

The project has four main objectives:

OBJECTIVE 1: DEVELOP A METHOD FOR INCREASING THE SUGAR CONTENT OF OIL PALM SAP

The first objective is to develop a method for enriching the sugar content in the sap contained in oil palm trees. Normally, the sugar concentration of sap is about 5–10%, but the sugar content of OPT containing starch increases two to three times by storage and treatment after cutting. Enriching the sugar content of the sap can increase the material value of oil palm tree and thus enhance its commercial value by reduced processing costs. By educating plantation operators on the mechanism for this sap concentration, and establishing improved management practices, the sugar content can be stabilised, making it possible to produce a higher value-added commodity.

OBJECTIVE 2: PROMOTE THE STRUCTURAL TRANSFORMATION OF THE PALM INDUSTRY

The second objective is to promote the structural transformation of the palm industry by realising the deployment and commercialisation of oil palm tree products. Initiatives being developed under this objective include high value-added products such as bioplastics and proteins, as well as fuel pellets, composite materials of woody biomass and plastics, MDF, etc.

In addition, oil palm tree sap can be converted into raw materials for bioplastic products (polyhydroxyalkanoic acid), fertiliser (calcium, magnesium, and potassium components contained in sap), and edible protein.

OBJECTIVE 3: EVALUATE THE EFFECTS OF LEAVING FELLED OIL PALM TREES ON PLANTATIONS

The third objective is to evaluate the effects of leaving felled OPTs on the dynamics of soil pathogens and the generation of GHGs. The aim is to establish a solid base for incentivising farmers to adopt technologies to utilise the felled OPSs in lieu of leaving them as waste.

The amount of GHG released from the decomposition of felled OPTs has been monitored since 2019. The preliminary findings show that CH_4 with a greenhouse effect 25 times more potent than CO_2 is released into the atmosphere when oil palm trees are foraged by termites with intestinal symbiotic bacteria decomposing cellulose, and that poor growth of palm trees resulting from the spread of soil pests has compelled farmers to practice excessive fertilisation, resulting in N_2O emissions, which are about 300 times more potent than CO_2.

OBJECTIVE 4: DEVELOPMENT OF AN ANALYTICAL FRAMEWORK

The fourth objective is to develop an analytical framework for comprehensively assessing the sustainability of the entire palm industry when value-added technology for OPTs is employed at a commercial scale. While the Malaysian government has introduced the Malaysian Palm Oil (MSPO) certification scheme for the assurance of palm oil sustainability as an obligatory measure, the biomass residues and waste generated along the palm oil manufacturing process are currently not subject to certification. It is necessary to establish a sustainability assurance system for the whole oil palm value chain, including biomass and waste liquid produced in the palm oil manufacturing process.

Development of technologies to utilise oil palm trees

The development of OPT utilisation technologies is being advanced by the demonstration facility constructed by the IHI Group in Kluang, Johor, Malaysia.

For the sugar solution, the wastewater treatment process configured around the IC reactor was applied to test biogas recovery and wastewater purification. The IHI Group's IC reactors have a proven track record as industrial wastewater treatment equipment in food factories and can use the biogas obtained at the factories as fuel for gas engines and cogeneration to generate electricity in-house. By decalcifying the solid residue derived from OPTs, even on a pilot scale, it was found possible to produce pellets with a quality close to that of wood pellets.

The subsequent trial test observed 50 kWh of power generation. Assuming that the biogas generated in the OPT treatment process is converted into power; this corresponds to an electricity supply capable of running the pellet manufacturing process for 10 000 tonnes per year. This showcases a possible pathway for carbon-free biomass fuel.

FIGURE 66: OPT pilot scale plant in Malaysia in Malaysia

Development of technologies to process EFB and POME

In addition to the aforementioned pilot program, the IHI Group is also developing technology to utilise empty fruit brunches (EFB) and POME.

EFB TREATMENT PROCESS

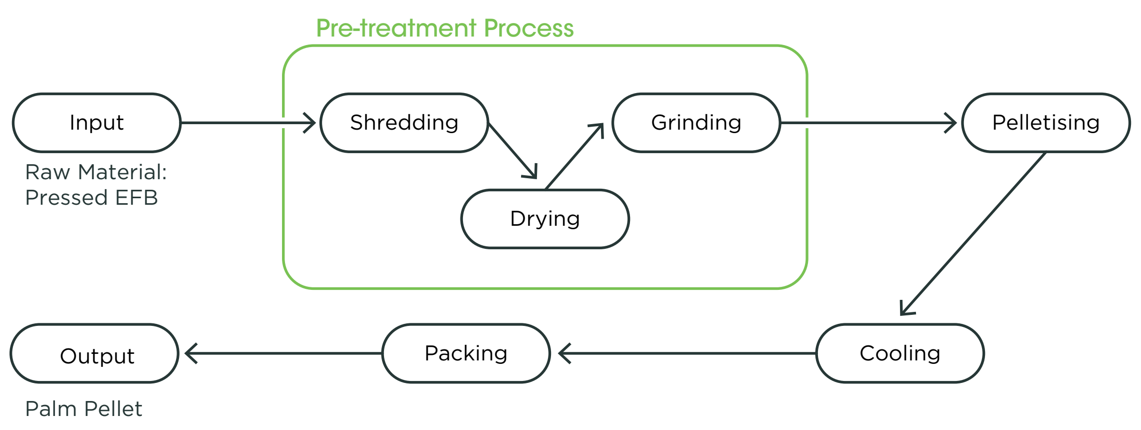
If EFB is dried and then burned, a large amount of oxidised soil-derived nutrients such as potassium oxide (K_2O) remain in the ash. These oxides melt at a relatively low temperature, causing heat transfer inhibition due to the adhesion of low melting point ash to the surface of the evaporation tube of the boiler. They are then entangled with the fluidised medium and form agglomerates in the fluidised bed furnace.

In order to utilise EFB as a biomass fuel whilst avoiding this issue, it is necessary to remove low melting point components such as potassium through pre-treatment (decalcification treatment). The pre-treatment also facilitates the removal of chlorine, which corrodes the furnace wall and heat transfer tubes.

Generally, the permissible amounts of these harmful components differ between dedicated combustion of biomass fuel and co-firing with other fuels. The project investigated the use of EFB pellets in the co-firing system, as the dedicated use of EFB pellets for power generation is not anticipated.

First, a new decalcification process involving drying, crushing and granulation was added to the conventional manufacturing process of EFB pellets. The result showed that the decalcification treatment reduced both the total amount of ash and the amount of potassium contained in EFB.

FIGURE 67: Flow chart for EFB pellets process



Source: Gemco Energy (2020)

Then, a method for predicting and monitoring the amount of potassium in EFB pellets after decalcification was examined for the purpose of introducing a quality control assurance system.

Emission spectroscopy is a method for directly measuring the amount of potassium in EFB pellets, but this is not suitable for quality monitoring because it is costly and difficult to measure in real time. Therefore, the IHI Group has established a model to predict the pellet quality based on the properties of the waste liquid by investigating the relationship between parameters that can be easily measured continuously, such as the potassium ion concentration in the waste liquid discharged from the decalcification process and the potassium concentration in the EFB pellets.

The combustion test of the prototype EFB pellets demonstrated that agglomeration starts to occur at a certain point when the co-firing rate of the EFB pellets is gradually increased, and it was found that the maximum co-firing rate at which agglomeration does not occur is related to the temperature inside the furnace and the low melting point component contained in EFB pellets.

The conclusion is that EFB can be converted into a biomass fuel without causing significant damage to the furnace by undergoing the decalcification process.

POME TREATMENT PROCESS

POME contains a large amount of palm oil that could not be removed during the oil extraction process and suspended solids (SS) derived from palm biomass. Since there is no effective wastewater treatment method, POME is a notable source of water pollution and GHG emissions in Southeast Asia. Removing insoluble components such as oil and SS by pre-treatment should be a critical step for treating POME. The wastewater treatment process adopted by the IHI Group is a three-stage treatment: pre-treatment using a centrifuge, IC reactor, and post-treatment (polishing plant).

First, the pre-treatment process is designed to separate POME into three different layers by the centrifugal machine. The oil contained in POME is discharged as a light liquid and then recovered. The solid-free POME is discharged as a heavy liquid and sent to the wastewater treatment facility for the following step. The solid content that has been consolidated and dehydrated by the screw after the centrifugation is collected and recycled as an organic fertiliser for the plantation.

Second, the internal circulation (IC) reactor removes organic components by methane fermentation of organic components contained in wastewater using a microbial mass called granule, and then recovers biogas. The wastewater treatment is generally performed by the activated sludge method using micro-organisms that breathe aerobically, but the disposal cost of surplus micro-organisms (sludge) in this case becomes high due to the need to aerate a large area in order to secure an oxygen source, incurring a considerable electricity bill. On the other hand, methane fermentation using an IC reactor can be more effective because wastewater treatment is performed under anaerobic conditions that do not require aeration, while the amount of sludge generated can be decreased due to the characteristics of anaerobic microorganisms.

The demonstration test of the above-mentioned POME processing system is being conducted at an actual-scale demonstration test facility installed in Pahang, Malaysia. As of August 2019, biochemical oxygen demand (BOD) values had been kept below

20 mg/litre for seven consecutive months, plus the target oil recovery amount was achieved by pre-treatment while the target biogas recovery amount in the IC reactor was also achieved. The concentration of methane gas contained in the biogas generated by this facility was about 80–85%, which was higher than the concentration of methane gas in the anaerobic lagoon system widely adopted in Malaysia (50–60%). The higher the methane gas concentration, the smaller the refining equipment, so investment can be reduced by this system.

Integrated palm oil biomass utilisation system

The abovementioned three types of palm biomass treatment technologies for EFB, POME and OPT have been developed by the IHI Group based on their respective stand-alone approaches. However, it has become clear that integration of these technologies is also possible. For example, EFB discharged from an oil mill contains a large amount of oil, and squeezing and centrifuging EFB would make highly efficient oil recovery possible. If the oil-free EFB is produced, it can be easily processed into pellets while POME's pre-treatment technology can be applied to oil recovery. The oil recovered from the EFB can be used as fuel oil for biodiesel.

It should also be noted that the technologies used to create pellets from EFB and OPT can be used interchangeably. If a standard process is established, both EFB and OPT can be processed more flexibly to meet fuel demand. In addition, conversion technologies for EFB and OPT into more value-added materials can be developed more efficiently.

Waste liquid discharged from the EFB and OPT processing processes can also be treated by merging with the POME processing process. At an EFB-POME-OPT total solution plant, it is also possible to produce biomass fuels such as EFB and OPT with a lower environmental load using biogas generated from POME processing equipment.

By integrating these processes, it becomes possible not only to improve investment efficiency, but also to efficiently generate renewable energy. This approach contributes to the development of a sustainable oil palm industry.

Overall findings

Oil palm trees have properties that make agricultural residue produced on oil palm tree plantations difficult to re-use.

Oil palm trees have a water content of 70% or more, where the liquid contained within the trees is high in sugar, containing a large amount of glucose, sucrose and fructose. The treatment process of such a high-concentration waste liquid is expensive. The remaining 30% of the oil palm tree log is solid and is rich in cellulose and starch, but the density of the dried OPT log is about 0.35 g/cm^3, on average, making it inefficient to transport.

Agencies across the region have collaborated to develop processes that provide a cost-effective approach to re-using oil palm tree residue. This case study presents four projects currently piloted by different organisations, indicating that there is interest within the market to find cost-effective treatment processes for oil palm tree residue. The pilot projects presented above show that there are viable solutions to convert oil palm tree residue into suitable biomass feedstock, though this has yet to be achieved at a large scale.

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