Foreword

Indonesia is the largest country in Southeast Asia. With a challenging geography, growing population and rapid economic expansion, the country is facing major challenges. That includes the choice of sustainable solutions to meet growing energy demand. Energy is an important and decisive enabler for promoting economic development and welfare. Therefore, the choice of sustainable energy solutions must be fully integrated in sustainable development strategies.

The project *Strategies for sustainable bioenergy development in Indonesia* was implemented between January 2014 and December 2017. It is part of a strategic cooperation between Swedish and Indonesian partners, more specifically the *Indonesian-Swedish Initiative for Sustainable Energy Solutions (INSISTS)*. The Project builds upon the interest of the Indonesian Government to harness the bioenergy potential of the country in a sustainable manner, and it aimed at providing support in that direction. In this context, issues of energy security, climate change and energy access for development were addressed. We particularly focused on segments that offer larger opportunities in terms of industrial synergies, climate mitigation, economic value added and welfare creation, while considering sustainability.

The Swedish team included researchers from KTH Royal Institute Technology and SEI (Stockholm Environment Institute). The Project was developed in cooperation with Indonesian partners including the Indonesian Energy Council (DEN), Gadjah Mada University (UGM), Indonesian Oil Palm Research Institute (IOPRI), and Indonesian Sugarcane Plantation Research Center (P3GI). The Project was funded by the Swedish Energy Agency (SEA).

This report provides details on implementation of the Project, and highlights major outcomes and recommendations. Our research provides contributions to support the development of sustainable bioenergy in Indonesia. The report also explores next steps for a continued collaboration in this field.

Professor Semida Silveira

Project leader

Background and objectives of INSISTS bioenergy

Indonesia is the largest country in Southeast Asia. With a challenging geography, growing population and rapid economic expansion, the country is facing major challenges. That includes the choice of sustainable solutions to meet growing energy demand and shift towards renewables. Energy is an important and decisive enabler for promoting economic development and welfare. Therefore, sustainable energy solutions must be fully integrated in sustainable development strategies.

Policies are in place to promote mandatory targets for biofuels, special electricity tariff for bio-based electricity generation, introduce small-scale biogas in rural areas, and improve the sustainability of the palm oil industry, among others. Some actions have been strongly criticized due to negative environmental impacts, such as the allowed expansion of oil palm plantations on forest land. Specific efforts and monitoring measures are needed to make sure that the deployment of modern bioenergy and biofuels takes a sustainable path. Only then can such development generate economic value and welfare without jeopardizing future opportunities. Science-based policy can contribute in this direction.

The program INSISTS (Indonesian-Swedish Initiative for Sustainable Energy Solutions) offers a platform of cooperation between Sweden and Indonesia on energy-related topics. The project *Strategies for sustainable bioenergy development in Indonesia* is an integral part of the INSISTS. So far, the Project has explored bioenergy pathways by developing analysis that link policy objectives with actions for medium and long-term impact. The overarching objective is to contribute to a sustainable deployment of bioenergy as a means to generate sustainable development and multiple benefits at global, national and local levels. In this context, the Project provides scientific analysis and evidence to support policy makers as they develop policies and strategies, and establish monitoring tools for bioenergy utilization.

This summary presents some highlights of the scientific work conducted by the Energy and Climate Studies (ECS) group at KTH Royal Institute of Technology and partners, with particular focus on palm oil and sugarcane bioenergy systems. We summarize key lessons and policy recommendations to help transform bioenergy systems in Indonesia into a sustainable energy option for the country.

The bioenergy landscape in Indonesia

Indonesia's energy system is largely fossil-fuel based. At present, the country is the second largest oil importer in Southeast Asia. The share of modern renewables is still limited. Energy demand may increase by 7-8% per year over the next decade according to the Ministry of Energy and Mineral Resources (MEMR). Approximately 15% of the population in Indonesia still lack access to electricity.

Traditional biomass dominates in cooking and thermal services. Only 5% of the total energy supply comes from modern bioenergy, mostly in the form of biofuels (MEMR, 2016). The role of bioenergy is changing rapidly as a result of policies adopted and revised since 2006.

The government of Indonesia sees bioenergy as an attractive option to promote socio-economic development and improve energy security. A major target is set for biofuels aimed at fuel blending: 30% biodiesel and 20% bioethanol by 2025. However, these targets require increased feedstock production to meet market demand. Thus, a stringent strategy is needed to guarantee the sustainability of the biofuel sector.

Except for palm oil biodiesel in the transport sector, the adoption of biofuels has been slower than anticipated, and there is a real risk that the final target may not be achieved (see Figure 1 and Figure 2 for projections and achievements in biodiesel policies). Reasons for the slow penetration can be found in national bottlenecks, and the interplay of local practices with the global climate and development agendas. Joint efforts are needed to guarantee that the bioenergy development in Indonesia can evolve with multiple benefits as has been observed in countries such as Sweden and Brazil.

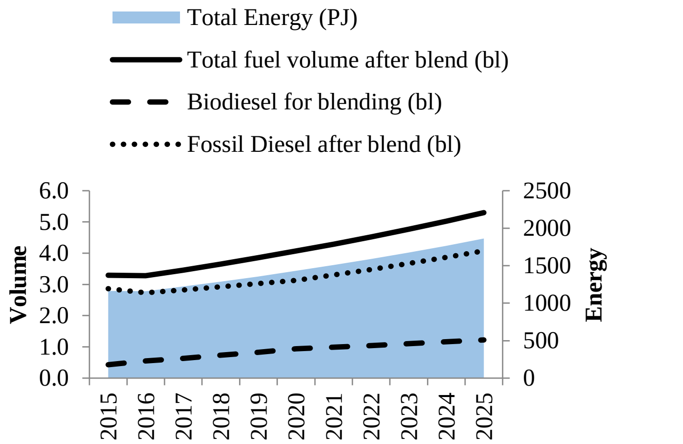

Figure 1

Projected diesel demand in Indonesia

in volume of the energy carrier (left axis) and
total energy (right axis).
Source: (Khatiwada, Palmén, & Silveira, 2018)

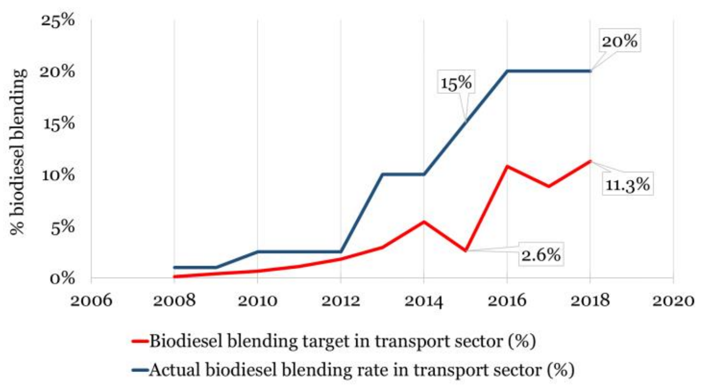

Figure 2

Progress in meeting biodiesel blending targets in the transport sector of Indonesia

Source: (Harahap, 2020a)

In terms of bioelectricity from biomass and biogas sources, the government target is to reach an installed capacity of 5.5 GW electricity by 2025. As of 2018, the installed capacity of bioelectricity was 1.8 GWe (or 5.3% of the total potential), fulfilling 33% of the target for 2025 (Maulidia et al., 2019; MEMR, 2019; Yudha et al., 2019). The palm oil industry produces 0.5 GWe from biomass combustion and biogas from methane capture for electricity production. Until 2015, only 3.6% and 1.06% of the total electricity potential from biomass and biogas sources, respectively, were found in palm oil mills in Indonesia (MEMR, 2016b). Thus there is still a long way to the target. The special tariff provided for electricity generated from biomass and biogas sources (Regulation 12/2017) has not been sufficient to realize the full potential of bioelectricity.

Bioenergy potential in Indonesia

Located in a tropical region, Indonesia is endowed with abundant biomass resources. Increased ability to deploy modern bioenergy can potentially contribute to positive impacts such as improved energy security, welfare and capacity to meet greenhouse gas (GHG) mitigation commitments.

The spatial distribution of biomass residues from various crops can be visualized in Figure 3. Palm oil and paddy together provide over 70% of the potential 2000 PJ available from residues. The remaining potential is distributed to maize, sugar, cassava and coconut (Palmén et al., 2016). There is good synergy in terms of geographic distribution and seasonal variation between paddy and sugar, but also maize. These justifies planning for efficient energy conversion over the whole year.

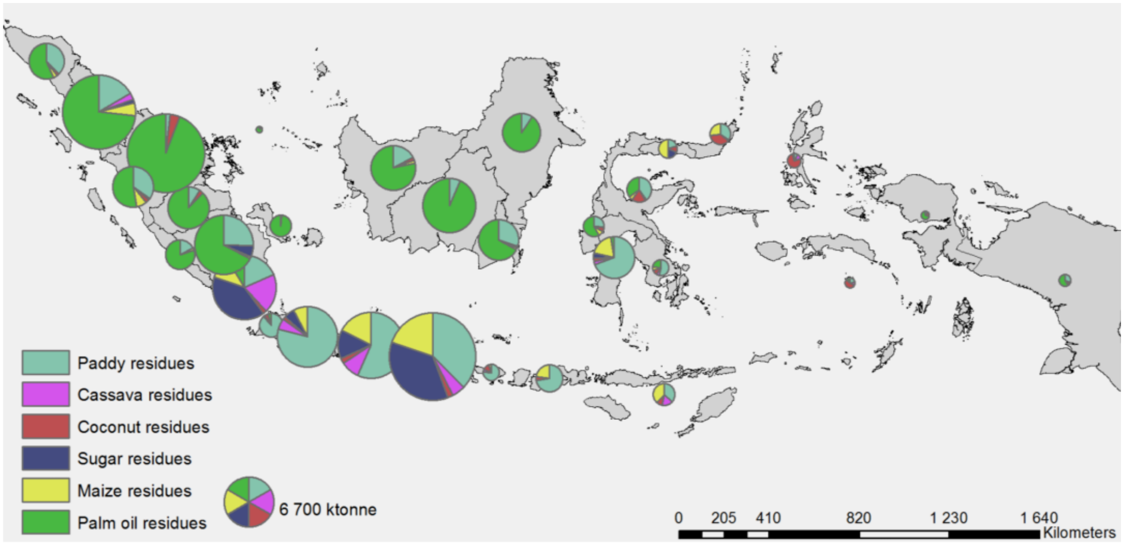

Figure 3: Crop residues available in Indonesia which can be used for bioenergy. The different sizes of the circles indicate mass of residues available in each region. Source: (Palmén et al., 2016)

Agricultural crops and residues are currently being utilised for liquid biofuels and bioelectricity in Indonesia, but the potential is much larger as can be gathered from Figure 3. A main preoccupation is to combine local resource potential with competitive technological options to provide modern and reliable energy services and, at the same time, promote sustainable development. This requires not only a transition from traditional use of biomass to modern bioenergy technologies, but also measures to guarantee a sustainable model for harnessing and using bioenergy.

Currently, only first generation biofuels are produced at industrial scale in Indonesia, mostly palm oil based-biodiesel. Second-generation biofuels can be produced from a variety of biomass sources such as wood, residues and waste, and so-called third generation biofuels can be derived from algae. These options can be explored as the country develops an integrated strategy for bioenergy.

Palm oil-based biodiesel

Palm oil is an important commodity for Indonesia. It meets domestic needs for food and non-food use, and is also a major source of export revenues. Hence domestic and export demand should be taken into account when estimating future demand for crude palm oil (CPO).

To meet the 30% biodiesel blending target in 2025, 12.2 billion liters of biodiesel are needed.

Photo: Palm oil harvesting

Source: MoA, 2015

To remain a major supplier of CPO both internally and at the global level, Indonesia will have to expand CPO production significantly. The total CPO production will have to reach 51.1 Mtonne in 2025.

In Indonesia, land for growing palm biodiesel feedstock is directly competing with land needed to guarantee food supply, forest conservation and climate change mitigation. In *agriculture policy*, land is needed for planting food crops to ensure food security, targeting an annual growth of 2-5% of agricultural crop production by 2019. In *biofuel policy*, land is allocated to produce feedstock needed to achieve a biodiesel blending rate of 30% by 2025, and improve energy security. The *climate policy* aims at reducing 23% of GHG emissions from business as usual by 2020 which is to be achieved by avoiding land use change in forests and peatland. In addition, sustainable use of forest products as specified in the *forestry policy* requires improved forest management.

Our research on prerequisites to meet the palm oil biodiesel blending targets in Indonesia investigated scenarios for domestic and international demand of CPO, in line with the biofuels mandate in the country, and established export markets. Increasing agricultural yields should be considered when contemplating options to meet palm oil demand. It could bring multiple positive effects, including reduced pressure on land, protection of forests and biodiversity, reduction of emissions and improved output from the land. In addition, a higher yield can help lower production costs for biodiesel, making the implementation of blending targets more cost-efficient. Yield improvement can be achieved through best management practices in cultivation and harvesting, complying with certified sustainability criteria, and improving quality of fresh fruit bunches. Palm oil standards and certification schemes, namely the Roundtable on Sustainable Palm Oil (RSPO) and Indonesia Sustainable Palm Oil (ISPO), are in place, but it is important to harmonize sustainability criteria and standards, including definitions, unified and coherent methodologies, and verification and monitoring procedures.

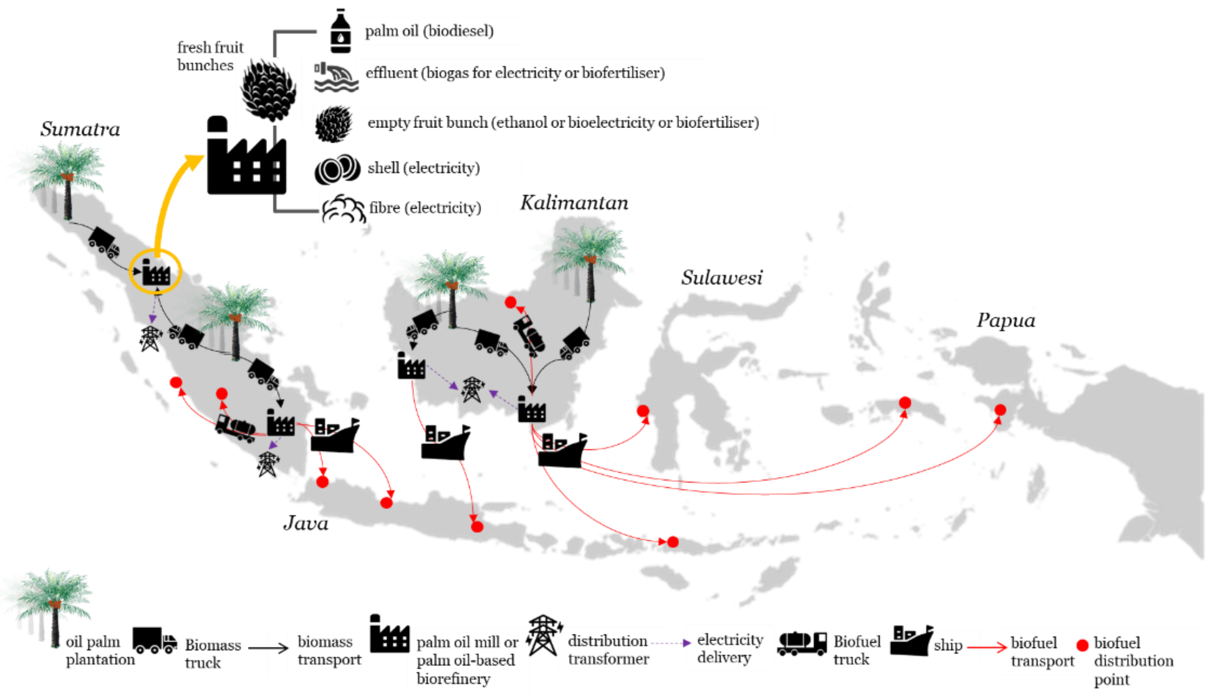

Figure 4: Graphical representation of the palm oil biomass-to-bioenergy supply chain in BeWhere Indonesia.

We develop a spatio-temporal optimisation model to examine the case of the palm oil supply chain in Indonesia (BeWhere Indonesia). The graphical representation of the model is presented in Figure 4. We consider the requirements for residue treatment (i.e., methane capture from POME, power generation from solid biomass, and biofertiliser production from EFB and POME) set by the Indonesian government are considered in the analysis. The research on pathways for harnessing the palm oil biomass potential, enhancing resource efficiency and meeting national energy and climate goals illustrates the multiple benefits of a sustainable palm oil-based industry. The results can be used to identify optimal options (technology and location), thus providing alternatives for policies and incentives to promote investments in biorefineries.

The improved sustainability performance in the palm oil industry is instrumental and urgently needed to address multiple sustainability challenges currently faced by the industry. Improving the sustainability of the palm oil industry will not only open international markets for Indonesian products but also guarantee the cost-efficiency of the palm oil industry. This could pave the way for an enhanced role for the Indonesian palm oil industry in global sustainability efforts.

Sugarcane-based bioenergy

Sugarcane is a major crops in Indonesia. Sugarcane-based production systems comprise the production of sugar and co-products (i.e. molasses and bagasse). Molasses is a low-value co-product that can be used for the production of fuel ethanol. Sugarcane juice can be diverted for the production of ethanol when there is surplus sugar-cane feedstock. Bagasse is combusted to provide energy (i.e. steam and electricity) for the plant. With improved efficiency, more electricity can be produced and added to the grid.

Photo: Sugarcane plantation
Source: MoA, 2015

The government of Indonesia established an ethanol blending mandate of 20% for transport and industrial sectors (see Figure 4 for ethanol required to meet the mandate). At present, given the lack of ethanol infrastructure, feedstock supply gaps, and the general focus on diesel, the ethanol production is negligible.

Lack of modernization of sugarcane systems, including cultivation practices and industrial operations, along with increasing competition are the main reasons for decreased performance of the sugarcane agro-industries. In Indonesia, most of the sugar mills are old, and 65% of them have been operating for more than 100 years.

Sugar production for self-sufficiency and ethanol for meeting mandatory bioethanol blending targets can be pursued simultaneously using suitable sugarcane land in the time frame between 2015 and 2025 (see Figure 5). Sugarcane land areas of 1.60 Mha and 2.76 Mha are required for meeting the dual objectives of sugar self-sufficiency and bioethanol mandates by 2020 and 2025, respectively. Besides sugar and ethanol production in sugarcane mills, there is abundant potential to produce bioelectricity when sugarcane biomass (bagasse and trash/residues) is efficiently used in combined heat and power plants.

The productivity gains accrued from the modernization of agricultural and production systems will benefit both food and fuel production, whereas bioelectricity generated from the sugar-ethanol industries can help diversify energy sources, and improve the economic competitiveness of the sector. In addition, renewable bioelectricity from sugarcane biomass provides an attractive way to reduce fossil fuel energy and emissions, and promote electrification. Improvements in agricultural management practices as well as supply-chain logistics are necessary for increasing sugarcane production and yield.

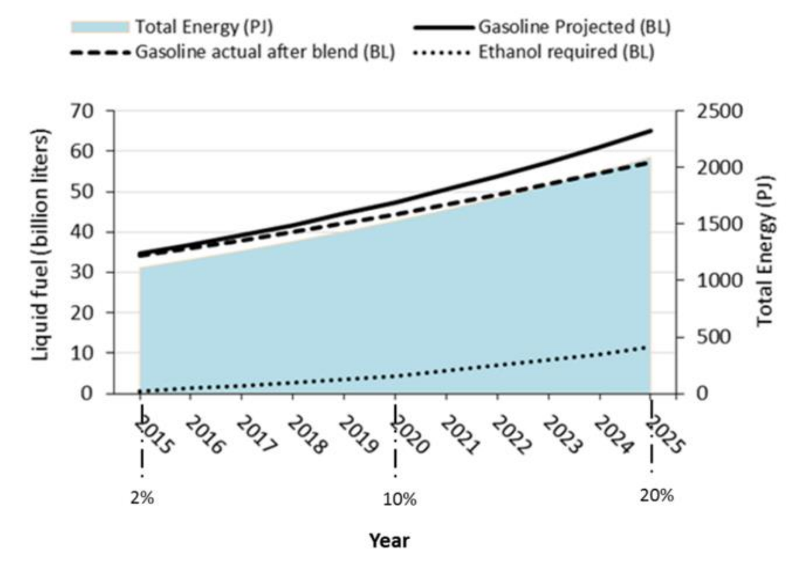

Figure 4

Gasoline and ethanol projection as per transport energy demand and blend mandates.

Source: (Khatiwada & Silveira, 2017)

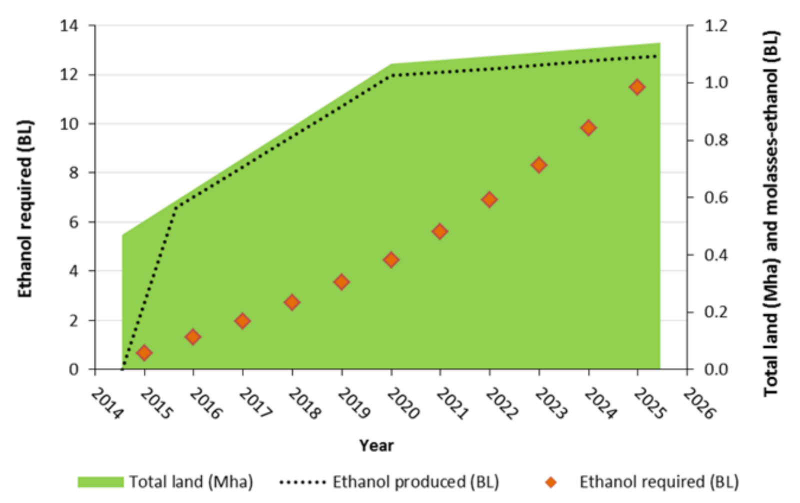

Figure 5

Total land required (Mha) for meeting sugar self-sufficiency and molasses ethanol production potential (BL)

Source: (Khatiwada & Silveira, 2017)

Project highlights and recommendations

<u>Spatial and temporal distribution of agricultural residues offer opportunity to improve security of feedstock supply for bioenergy</u>

The majority of the agricultural residues in Indonesia are generated by the palm oil industry followed by paddy cultivation. Paddy residues have good spatial and seasonal synergy with sugar and maize residues which, in combination, can provide an even biomass supply along the year. The seasonal and spatial distribution of biomass residues can help optimize biomass for energy conversion.

Cross-policy analysis and monitoring is needed to determine the amount of land available to meet biofuels goals and other sectoral policy goals

Sectoral coordination is important, especially when dealing with basic resources or materials such as land and water. Land plays an important role in the implementation of agriculture, climate, forestry and energy policies. According to our analysis, the area available for meeting each sectoral policy goal when taking into account cross sectoral interactions is: 14.2 Mha for agriculture, 43 Mha for climate mitigation measures, 9.2 Mha for forestry, and 20.9 Mha for biofuels. Three measures are proposed to improve synergies of sectoral policy goals in terms of land use. First, uniformity is needed in land use definitions. Presently, there is ambiguity when it comes to land categories being used. In particular, there is urgency to more clearly define *degraded land* and *peatland*. Exclusion of peatland eligibility should be considered at least until more is known about the environmental impacts associated with their use. Second, land use classifications need improvement for consistency in official policies. Third, a publicly available database would enhance the efficiency of land allocation and pave the way for the effective implementation of multiple policies, while also offering an instrument to better formulate and monitor land use. The lack of solid data in Indonesia is still a major obstacle for policy design and monitoring.

The amount of land needed to meet the biodiesel blending target can be reduced through increased agricultural yields

Indonesia can meet its domestic demand for CPO until 2025 using the equivalent to 63% of the oil palm planted area in 2014 if present average yield is kept. However, to meet both domestic and international demand, a total 51 million tonnes of crude palm oil will be needed in 2025. This requires 6 million hectares of additional land with current yields. A strategy for increased productivity in palm oil production, utilization of degraded land to contain greenhouse gas emissions, and use of palm oil biomass residues for energy production should be pursued. This will benefit biodiesel production while reducing the need for new land.

A biorefinery configuration to produce various bioenergy products (biodiesel, electricity, and ethanol) can improve the cost and resource efficiency of the palm oil industry

Dependency on government subsidies for supporting the biodiesel industry can be reduced if a strategy to develop bio-refineries is pursued. Part of the subsidy budget could be directed to promote industrial integration. This would reduce the industry's vulnerability to diesel price fluctuations and make it more competitive. Value chain integration can contribute to achieve higher resource efficiency, enhance penetration of renewables, and reduce GHG emissions from fossil fuel use and untreated residues. This contributes to policy objectives and climate commitments.

Improving the current practices on palm oil biomass utilization is significant for meeting the national bioenergy and climate targets

For bioelectricity, 0.84–1 GW_e can be produced in palm oil-based biorefineries in Sumatra and Kalimantan. This implies that the industry can meet 15%–19% of the target for bioelectricity installed capacity in 2025. There is a higher potential to generate excess electricity when all mills are connected to the power grid. Improvement in grid connections in Sumatra can provide the basis for an installed capacity of bioelectricity plants equivalent to 2.8 GW_e, meeting 50% of the national bioenergy target by 2025. This also means covering 50% of the electricity demand of Sumatra, helping the island to reduce its dependence on highly fossil fuel-based electricity. The biomass-to-electricity potential is significant and could play a major role in the development of electrification in Sumatra and Kalimantan (the current electrification rate is below 90% on these islands). When it comes to the biodiesel target (30% biodiesel blending with diesel in transport, industry, and power sectors in 2025), between 4.4 and 10 bL of biodiesel can be produced, reaching 44%–98% of the target. The lowest biodiesel production is found when limited amounts of CPO can be used for biodiesel production. The highest biodiesel production (10 bL/y using 9 Mt_{CPO}/y) is obtained when the technology investment cost is reduced. Finally, 2.2–4.5 bL of ethanol can be produced in 2025. This means that the industry can meet 17%–35% of the ethanol target in 2025 (20% ethanol blending with gasoline in the transport sector).

From the point of view of emissions reduction in the waste sector, the contribution to meet the climate target is tremendous. Emissions avoided through efforts to manage POME in Sumatra only can be up to 22 $MtCO_2eq$/y. This demonstrates that efforts to improve POME treatment and management in Sumatra can help to achieve the emissions reduction target set for the waste sector in the unconditional mitigation scenario (i.e., 11 $MtCO_2eq$/y) and nearly all of the emissions reduction in the conditional mitigation scenario (i.e., 26 $MtCO_2eq$/y) by 2030. This might be an indication that there are opportunities to set a higher targets for reducing emissions from the waste sector.

Government support is the key to shift from the traditional practices in the palm oil industry

A necessary condition to maximise the environmental benefits from utilising palm oil biomass residues is the establishment of grid connectivity to palm oil mills. The establishment of infrastructure to connect more palm oil mills to the grid can stimulate investment in electricity capacity at mills and promote more efficient use of biomass in highly efficient biorefineries. This would have a decarbonising effect on the power sector. Significant government support will be needed to trigger development in this direction. Support can come in the form of technology demonstrations and installation investments, price monitoring for bioenergy products, and fiscal policies. Carbon taxes can make bioenergy technologies, such as biogas, more attractive. The government should phase out the subsidies still provided to fossil diesel, and possibly direct those to promoting a clean fuel program. The capital required for upgrading biomass conversion technologies and enhancing power grid connections to palm oil mills could be partly offset by emissions reductions if a carbon market is established.

Forging partnerships between oil palm plantations, the palm oil mills, and energy producers can ensure the development of sustainable industrial practices

It is crucial to make the palm oil mill owners aware of the opportunities at hand to incorporate energy production in their business models. New skills and collaboration with independent power producers can pave the way to harness the full potential of bioenergy and promote investments. Various programmes for forging partnerships between oil palm plantations, palm oil mills, and energy producers are necessary to ensure the development of sustainable industrial practices. The upstream (oil palm plantations) and the midstream (palm oil mills) industries have been able to operate at a profit. In contrast, the downstream industry (bioenergy producer) needs to work further on its industrial and financial model to become an attractive proposition for investors.

Integrated sugar and biofuel programs can bring multiple benefits

The targets for sugar and ethanol have not been followed by detailed implementation plans, thus bioethanol deployment remains uncertain. Sugar production for self-sufficiency and ethanol for meeting mandatory bioethanol blending targets can be pursued simultaneously using suitable land between 2015 and 2025. To harness the potential of sugarcane-based energy systems, integrated plans shall include sugarcane expansion in suitable land, modernization of mills and investments in bio-refineries, as well as infrastructure for blending and distributing biofuels. Improved resource efficiency can be achieved through bioelectricity production from sugarcane biomass, improvements in yields, and modernization of sugarcane mills. The productivity gains accrued from the modernization of agriculture and processing systems will benefit both food and fuel production, whereas bioelectricity from sugarcane biomass provides an attractive way to reduce the use of fossil fuels.

Climate change impacts affect suitability of areas for sugarcane and rice paddy and potential for bioenergy

Climate change may affect sugarcane cultivation and productivity, thus requiring climate adaptation measures. Both rainfall and temperature variations are important for cane growth. Areas on East Java are expected to experience higher temperatures and are of particular interest for sugarcane plantations. The most appropriate areas to expand or intensify cultivation are around the mountainous regions where rainfall and temperature are likely to be favorable in the future. Lowland areas, which cover a wide area in East Java, also offer opportunity for sugarcane expansion.

The implications of climate change for rice paddy in Bali could also be significant and affect food availability. The southern coast is threatened by lower rates of precipitation, while regions around the mountains are constrained by temperature. Lack of rainfall poses large risks for rice paddy, more than temperature variations. Planning for adaptation actions should be taken to mitigate vulnerability, as the regions with higher productivity today are likely to be exposed to climate change.

Three scenarios that could encourage bioethanol production in Indonesia, have been identified based on interviews and FGD among stakeholders at the provincial level, in East Java by using XLRM framework. The first scenario revealed the collaboration at the Niche level that includes farmers, sugar factories, ISRI and BMKG through a potential activity of the Climate Smart Agriculture for sugar cane. The second scenario suggested the impact of global crude oil price and bioethanol policies could incentivize the use of bioethanol. The third scenario emphasized the importance of Government´s priority in including bioethanol as a part of national energy target. Additionally, further effort would be required such as providing a secure bioethanol infrastructure and market for buyers, in order to keep bioethanol producers in existence.

Lessons from leading bioenergy producing countries suggest the need to look beyond the energy sector when planning for bioenergy deployment

Bioenergy use in both Sweden and Brazil reflects the benefits of system integration between energy and other sectors such as forestry and agriculture, and increasingly also chemical industries and waste management. Mobilization of public and private stakeholders, definition of goals and policies to catalyse investments, market creation and provision of additional infrastructure have been essential in the development process. Coordinated efforts on both supply and demand sides, R&D and strong interest groups helped push technology options and markets. These efforts have led to world class achievements in bioenergy deployment and market development. Long term commitments create the virtuous cycle of private and public investment in both infrastructure and institutions, which characterizes the upscaling phase of successful technology deployment, and the evolution from niche to mainstream technology.

The road ahead

In Indonesia, bioenergy has been clearly recognized as an important modern renewable energy source. Still efforts need to be intensified in terms of policies, incentives and coordinated actions around a strategy to guarantee a sustainable transition from traditional practices to modern and sustainable solutions.

Certainly, the country is poised to take an important global role in the transformation of the palm-oil based industry. A holistic approach will improve competitiveness, leading to enhanced energy service provision and improved energy self-sufficiency. Pathways have to be defined including roadmaps and strategies to guide the development of bioenergy and its integration with other sectors, improving resource efficiency and reducing environmental impacts.

The synergies between agricultural and industrial sectors are key to success in face of competing uses for land and water, the need for improved resource efficiency, and efforts to guarantee both food and fuel supply. The global climate benefits provide further incentive for Indonesia to explore its bioenergy potential.

In the mid-term, bioenergy deployment may focus on the conversion of biomass into marketable bio-products and energy. This can be done through modernization of agro-forestry industries, for example, using bireofneries for multiple products and energy services (e.g. liquid biofuels, biogas, bioelectricity, feed). The production of multiple bioenergy produts provide opportunities for meeting energy targets while also improving the social, economic and environmental sustainability of the system.

While first generation biofuel production can help increase the bioenergy share in Indonesia, second-generation options should be explored in the long-term to improve resource efficiency and reduce emissions, as well as delink the expansion of bioenergy production from the expansion of energy crops. Furthermore, sustainable bioenergy production from degraded land can reduce conflict with other food crops.

Finally, it is important to explore development towards a bio-based economy, with integrated resource utilization for harnesing the full potential of bioresources in Indonesia. Linking bioenergy markets and ecosystem services to provide energy services, improve energy security and promote sustainable livelihoods should be seen as mutually reinforcing objectives to promote the sustainable development goals (SDGs) in Indonesia.

Policy dialogue carried out on *Developing science and evidence based policy and practice of bioenergy in Indonesia*, Bogor, Indonesia 2017