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Cultivating energy crops on former mining sites: A sustainable option for bioenergy use in Vietnam?

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List of Abbreviations

Abbreviation	Full Word
As	Arsenic
Cu	Copper
Cd	Cadmium
CH_4	Methane
Co	Cobalt
CO_2	Carbo Dioxide
Cr	Chromium
CIF Price	Cost Insurance Freight Price
ERAV	Electricity Regulatory Authority of Vietnam
EVN	Vietnam Electricity
GWh	Giga Wat hours
FM	Fresh Matter
Hg	Mercury
kg	Kilogram
kwh	Kilowatt-hour
LCOE	Levelized Costs of Energy
m^3	Cubic Meter
Mn	Manganese
MONRE	Ministry of Natural Resources and Environment
MOIT	Ministry of Industry and Trade
Ni	Nickel
Pb	Lead
Petrolimex	Vietnam Petroleum Group
Petro Vietnam	Vietnam Oil and Gas Group
TJ	Terra Joule
Vinacomin	Vietnam National Coal and Mineral Industries Group
Zn	Zinc

1. Introduction

With its dynamic economic growth and industrialisation, Vietnams energy demand is increasing rapidly. A large share of the country's current energy supply still derives from non-renewable energy sources such as fossil fuels. This leads to increasing environmental problems and contributes to climate change. However, due to the country's geographic and climatic characteristics, the potential for the expansion of renewable energy is high.

Besides wind energy and solar power, especially the production of bioenergy from biomass has a big potential in the country. Being locally available and storable, bioenergy can stabilise the energy system when wind power and solar energy are temporarily not available and can provide energy for those households that are not connected to the power grid. Furthermore, sustainably produced biofuels can contribute to the decrease of greenhouse gas (GHG) emissions in the transport sector.

Bioenergy can either be produced from manure and organic waste or from energy crops. However, the production of energy crops for generating bio-energy needs large areas of agricultural land. An expansion of cultivation areas for energy crop cultivation can therefore result in a direct competition with local food production contributing to growing food prices and possibly putting local food security at risk. In Vietnam, where arable land is becoming increasingly scarce due to the expansion of areas for infrastructure, industry, housing and recreation, sites for growing energy crops have to be selected carefully.

One option to mitigate the described conflict on available land is to foster energy crop cultivation on areas that are not attractive for food production, including marginal areas with poor ecological site conditions, poor water supply, terrain challenges, pollution, or low soil quality and fertility.

In this context, from 2015 to 2018, a German-Vietnamese project consortium implemented the first phase of the pilot project "Climate Protection through Energy Plants (CPEP)" funded by the International Climate Initiative (IKI). Due to an emerging rising demand for bioenergy in Vietnam during this time, the project aimed to show ways of increasing national biomass and bioenergy production without competing with food production while preventing further negative effects of land use changes (LUC). To this end, the project pursued the approach of using post-mining sites for the cultivation of biomass as feedstock for different bioenergy technologies. In Vietnam, such areas are numerous and cannot be used for food cultivation due to poor soil quality and possible contamination. On three pilot areas in the north and south of Vietnam, it was tested which energy crop systems are suitable to be cultivated on former mining sites.

In Vietnam, surface mining left and still leaves behind so-called „post-mining landscapes", large barren areas mostly bare of vegetation and partly polluted with heavy metals and other contaminants. According to the Vietnam Environmental Administration (VEA), there are around 4,000 mining sites throughout the country.[1] Former mining site areas are mostly not suitable for food production, which makes them interesting for other uses such as biomass production. In this context, the production of energy crops can be a suitable rehabilitation measure: It creates a vegetation cover on the formerly bare land, which can reduce wind and water erosion and therefore contributes to the enhancement of soil quality. It also promotes biodiversity through remigration of other plant species and animals, and leads to improved microclimatic conditions.

[1] Thuc (2015)

There are energy crop species that even contribute to the reduction of contaminants in the soil by absorbing them (so-called phytoremediation).

On the local and regional scale, bioenergy production is a suitable strategy for the reintegration of former mining sites into a non-mining utilisation cycle which can finally contribute to the diversification of the local residents' sources of income. On a national and global scale, the use of bioenergy from crops that were cultivated on former mining land can reduce GHG emissions if it replaces the use of fossil energy resources and avoids negative impacts on the climate through land use change (LUC) effects during the cultivation. In comparison with their fossil reference energy sources, in most of the cases, biofuels produce less GHG emissions. However, the theoretical emissions neutrality of bioenergy has to be seen critically, because in all steps of bioenergy production chains, including cultivation of energy crops, transport, and conversion from crops to energy, GHGs are emitted into the atmosphere. LUC is thereby one of the most significant drivers for negative environmental impacts from bioenergy production. LUC in the context of bioenergy production means the conversion of land that has been used for other purposes or has not been cultivated by humans before into land for the production of bioenergy crops. Hereby, two types of LUC can be distinguished: Direct LUC and indirect LUC.

Direct LUC occurs when bioenergy crops are cultivated on land that was previously not used for cropland or farming. This includes mostly natural vegetation areas (e.g. forests), but can also include set aside, underused, or degraded land (= marginal land). Indirect LUC occurs when the previous activity on the land shifts to other land induced by crop production for bioenergy purposes. Conversion of farmland for food production into land for biomass production usually leads to indirect LUC, because the previous food production is relocated into other areas, often areas of natural vegetation. Direct and indirect LUC both have significant negative effects on the environment including biodiversity, soils, and the climate.

The use of former mining sites for the production of energy crops, like it has been investigated within the CPEP project, aims at reducing these negative LUC effects from biomass production. The project's purpose was to demonstrate the feasibility of reusing closed mining sites in Vietnam for the cultivation of energy crops on a pilot scale on three different sites. The pilot sites differ in terms of location, type of mining activities, and climate conditions, including a waste rock dump from tungsten mining in Dai Tu, Thai Nguyen province, a waste rock dump from coal mining in Hon Gai, Quang Ninh province, and a site after bauxite mining in Bao Loc, Lam Dong province. On each of these pilot sites a different combination of energy crops was grown, including fast growing tree species (mainly acacia), sweet sorghum and cassava, specific grass species (VA06), and other energy crops. Besides the investigation of the feasibility of growing the selected crop species, the project aimed to draft potential utilisation pathways for the harvested energy crops in terms of their energetic use and their economic potential. For the most promising scenario, the potential effects for climate protection were modelled in the form of a life cycle assessment. The results will be presented in this UfU Paper.

2. Vietnamese legal framework on bioenergy and re-cultivation of former mining sites

The following chapter shortly summarises the current legal and energy policy framework in Vietnam with regard to the cultivation of energy crops on post-mining sites within the CPEP project.

2.1 Current legislation on biofuel development

In recent years, the Vietnamese Government has issued a number of policies to encourage the production of biofuels. In 2007, it approved Decision No. 177/2007/QD-TTg on the "Scheme on Development of Biofuels up to 2015 with the Vision to 2025" with the aim of developing biofuels as a new and renewable energy source to partially replace conventional fossil fuels, to assure energy security and to contribute to climate and environmental protection. According to Decision 177/2007 / QD-TTg, the output of ethanol and biodiesel will reach 1.8 million tons by 2025. The government has outlined solutions that focus on research and development, encouraging investments in biofuel technologies, building the potential for biofuel development through enhancing human resources, modernizing equipment and increasing international communication and technology transfer.
Decision No. 53/2012/QD-TTg dated November 22nd 2012 of the Prime Minister also established a roadmap for implementing the biofuel mixing ratio with traditional fuels. From December 1st 2015 and 2017, the gasoline produced, blended and traded for use by road motor vehicles for nationwide consumption should be E5 and E10 gasoline, respectively. In 2015, the Viet Nam Renewable Energy Development Strategy to 2030, with an outlook up to 2050, was approved by Decision No. 2068/QD-TTg dated November 25th 2015. One of the objectives of this Strategy is to increase the production of biofuels to meet 5% and 13% of transport sector's fuel demand in 2020 and 2030, respectively. In addition to this, since January 1st 2018, the Vietnamese Government has only allowed E5 RON 92 and RON 95 to be produced and traded in order to contribute to energy security gradually reducing the dependence on fossil fuels. It also includes the aim of protecting the environment, generating sustainable income for farmers, restructuring the agricultural sector and implementing the commitments of the Government of Vietnam to the global mitigation efforts. Under the impetus of recent policies, some achievements in biofuel production in Vietnam can be observed like the construction of a number of biofuel facilities. Nevertheless, this progress seems to slow down since 2015, because only 2 ethanol facilities of one company are still in operation.
In general, Vietnam has developed a sound legal system for the promotion of biofuels. However, a survey conducted by the Friedrich Ebert foundation cites energy experts and stakeholders who still emphasize a lack of policy implementation. Uncertainties for investors are increased by missing technical and administrative regulations.[2] Nevertheless, the current policy framework is still in favour of biofuel production thereby underlining the relevance for cultivating energy crops on post-mining sites within the CPEP project.

[2] Neefjes. Koos; Dang Thi Thu Hoai (2017)

2.2 Current legislation regarding re-cultivation of former mining sites

In the Law on Environmental Protection No. 72/2020/QH14 dated November 17th 2020, Article 15 clearly states that agencies, organizations, communities, households and individuals using land in Vietnam have the responsibility to protect the environment and treat, improve and restore contaminated soils. The State is responsible for treating, renovating and restoring the environment in areas with environmental pollution left behind by history, or if the organizations or individuals that are responsible for the pollution cannot be identified. Article 67 of the Law on Environmental Protection also stipulates that organizations and individuals that carry out the exploration, exploitation and processing of minerals and oil and gas activities are responsible for environmental rehabilitation.

According to Article 30 of the Mineral Law approved by Decision No. 60/2010/QH12 dated November 17th 2010, the organizations and individuals engaged in mineral activities are required to implement solutions and bear all costs of environmental protection, rehabilitation and restoration.

In 2013, the Prime Minister approved Decision No. 18/2013/QD-TTg on environmental rehabilitation and recovery and deposit for environmental rehabilitation and recovery for mineral exploitation activities. According to Appendix 1, mining companies are required to plant trees to cover the entire bottom surface of the pit. The selected tree species and varieties need to have a high economic value and to be suitable to local living conditions. Moreover, the planting rate must be equal to 40%-50% of the planting density and the restoration of ecosystems and vegetation must ensure the selection of species, varieties and quantities that are similar to those of ecosystems and vegetation before the exploitation.

In 2015, the Ministry of Natural Resources and Environment (MONRE) issued Circular 25/2019/TT-BTNMT on environmental rehabilitation and recovery in the mining exploitation activities to guide the implementation of regulations on environmental rehabilitation and restoration and deposit for environmental rehabilitation and restoration for mineral exploitation activities of Decree No. 19/2015/ND-CP dated February 14th 2015. According to Appendix 3 of Circular No. 38/2015/TT-BTNMT on guidelines for solutions for environmental renovation and restoration in mineral mining dated June 30th 2015, it is required to plant shrubs and trees and to green the entire field cover and the soil on the tops and slopes of the landfill. The Appendix also has specific requirements for tree plantation. The selected tree species and varieties also need to have a high economic value and to be suitable to local living conditions. In addition to that, the works of tree plantation and care requires a minimum of 3 to 5 years and the planting rate requires 10-30 % of the tree density.

Even though Vietnam has several legal documents on tree plantations on post-mining sites with specific requirements, there is currently no legal document on cultivating other usable crops such as energy crops on those areas. Nevertheless, mining companies are still obligated to conduct environmental rehabilitation activities on post-mining sites and thus might be interested in using energy crops as re-cultivation measure. In this way, mining companies have a double advantage, because they comply with national law and increase their profit by selling energy crops to biofuel producers. That's why, the CPEP project aims to give new insights on the cultivation and utilisation of energy crops on post-mining sites in Vietnam.

3. Status quo and development of the Vietnamese energy sector

Since the introduction of Doi Moi economic reforms in 1986, Vietnam underwent a rapid economic development. Due to the strong increases in the service and industrial sector, the country's GDP grew fast from 6.47 billion US$ in 1990 to 271.16 billion US$ in 2020.[3] As a result, Vietnams power mix started to change, while its energy demand and production constantly increased. In the following years, other drivers like urbanisation and income growth will further enhance this development.[4]
In Vietnam, the commercial energy consumption per capita is low, because in rural areas many people still depend on non-commercial biomass as energy source. Moreover, the country's commercial energy sector is not competitive but dominated by state-owned enterprises. Vietnam Electricity (EVN) is responsible for the power subsector and the Vietnam Oil and Gas Group (Petro Vietnam) as well as the Vietnam Petroleum Group (Petrolimex) explore and produce petroleum as well as hydrocarbon. The Vietnam National Coal and Mineral Industries Group (Vinacomin) is active in mining activities related to coal and minerals, including the construction and operation of coal fired power plants. All of them are supervised and managed by the Ministry of Industry and Trade (MOIT) and by the Electricity Regulatory Authority of Vietnam (ERAV).[5]
The following chapter gives an overview about the status quo and development of Vietnam's energy sector. Thereby, it deals with the power generation, fuel and bioenergy sector to demonstrate how the latter might complement the others towards a more sustainable energy sector in the future.

3.1 Power generation

The opening of Vietnamese markets due to the Doi Moi economic reforms in 1986 initiated the diversification process of Vietnam's energy sector with the goal of creating a socialist-oriented market economy. Figure 1 demonstrates this development by depicting the total energy supply in Vietnam from 1990 to 2019. It shows that Vietnam nowadays mainly depends on fossil fuels like coal, oil and natural gas as energy source, which accounted for 85% of the total energy supply of 3.8 million TJ in 2019. Even though renewable energy sources like solar, wind and geothermal power still play only a minor role in Vietnam's energy production, renewable energy from biofuels, waste and hydropower made up 15% of the total energy supply. This was different in 1990, when around 70% of the total energy supply came from biofuels and waste.[6] However, it can be assumed that in the past especially firewood was used as bioenergy source on the household level resulting in environmental damages like deforestation.

[3] IEA (2022a)
[4] World Bank Data (2017)
[5] Asian Development Bank (2015)
[6]IEA (2022a)

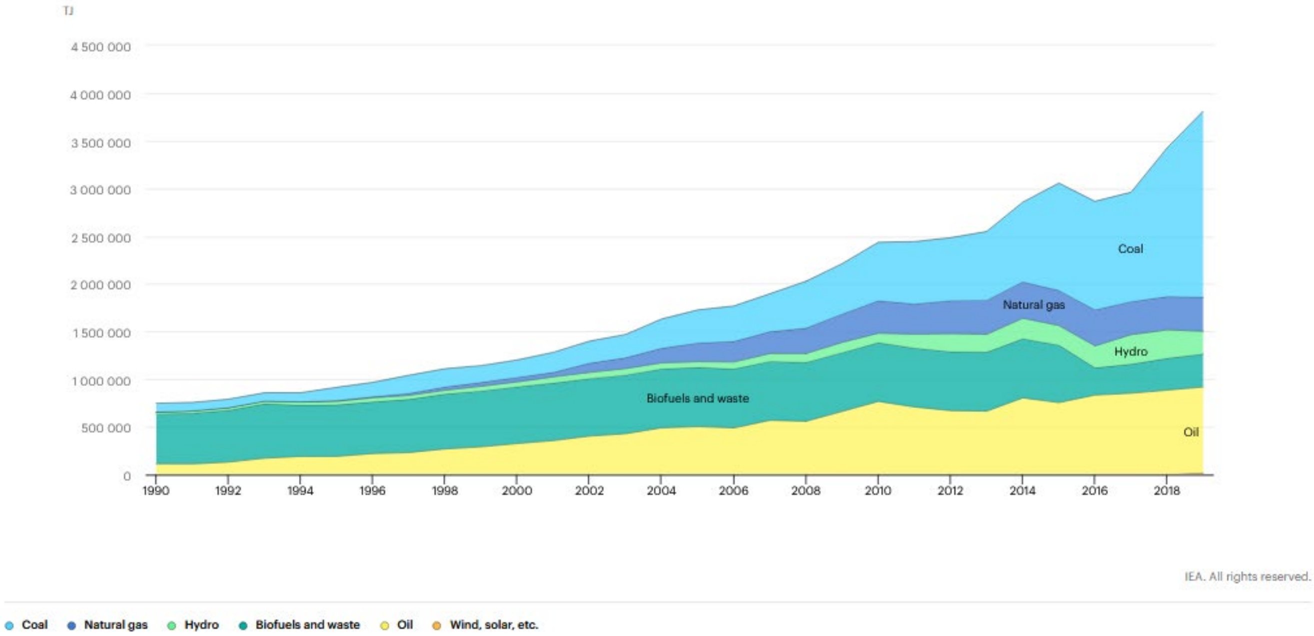

Figure 1: Total energy supply development in Vietnam (IEA 2022a)

In Vietnam the electricity generation strongly increased from 8700 GWh in 1990 to 225000 GWh in 2020 (See Figure 2).

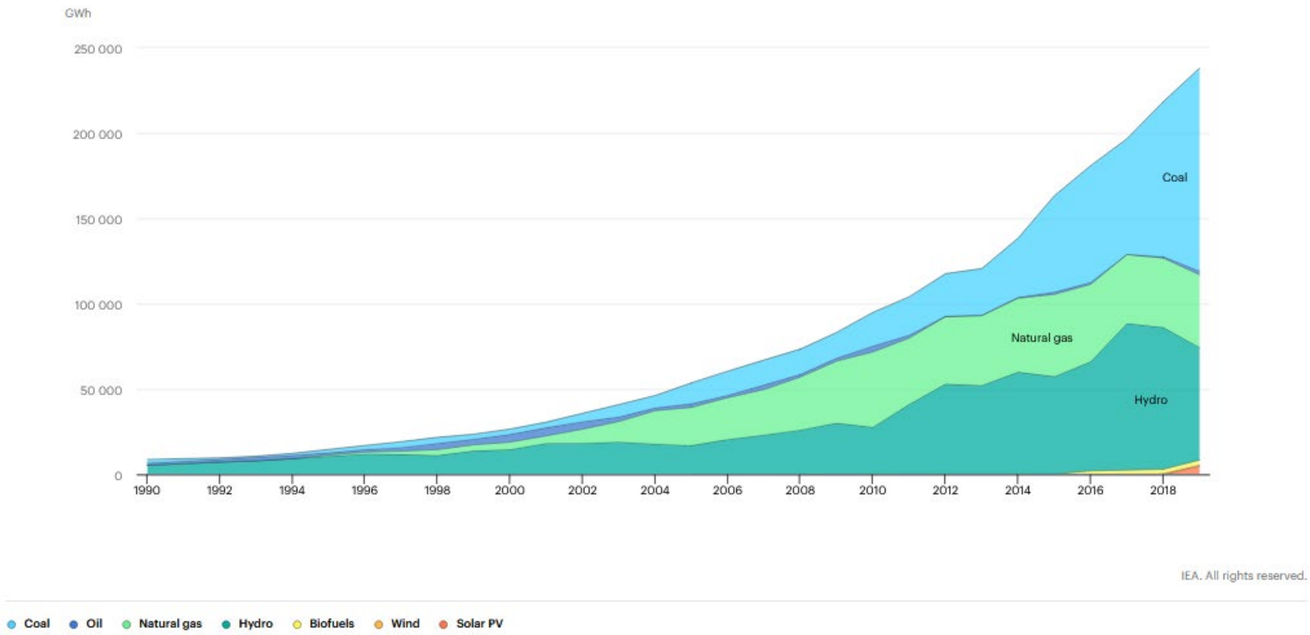

Figure 2: Electricity generation development in Vietnam (IEA 2022a)

In the 1970's, Vietnam's electricity demand was almost entirely met by coal, before oil and hydropower played an ever increasing role leading to a diversification of electricity sources. Since the late 1990s natural gas has been used, while oil-related sources nearly disappeared in the last 20 years.[7] Nowadays, Vietnam's coal supply for electricity production relies to a great amount on cheap imports from China, because the domestic exploitation is becoming increasingly expensive.[8] That's why the promotion of renewable energy for domestic energy production becomes more and more important.

Excluding hydro power, the share of renewable energy like biofuels, wind and solar power in the total energy generation has constantly increased since 2018. [9] Nevertheless, it just reached 3.7% in 2020, which is less than the 7% mentioned in the government's "Revised National Master Plan for power development for the 2011–2020 period with the vision to 2030".[10] In addition to that, in the "Renewable Energy Development Strategy (REDS) 2016-2030" there is a share of 35% of renewable energy planned for 2050, made up of 20% solar, 8% biomass and 5% wind power[11]. This further underlines the relevance of the CPEP project in promoting the cultivation of energy crops on post-mining sites as a means to increase the share of renewable energy in the total energy generation in Vietnam.

3.2 Fuel sector

Vietnams oil demand has constantly increased in the last 30 years reaching around 850,000 TJ in 2019. Gas/diesel and motor gasoline accounted for 48% and 36% of the total oil demand, respectively (Figure 3).

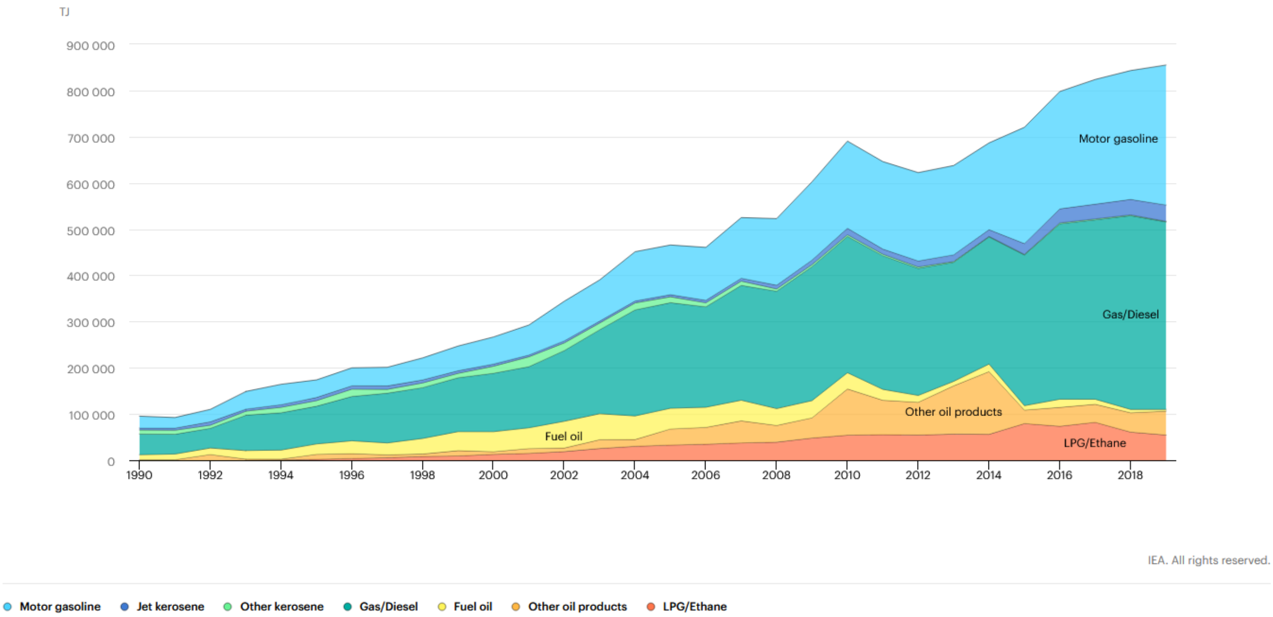

Figure 3: Oil final consumption development in Vietnam (IEA 2022a)

Vietnam is among the 52 countries with oil and gas potential in the world. By the end of 2015, its crude oil reserves were around 4.4 billion barrels while its gas reserves were approximately 0.6 trillion m³. Compared

[7] IEA (2022a)
[8] Minh-Ha-Duong et al. 2016
[9] IEA (2022a)
[10] GIZ (2017)
[11] Neefjes. Koos and Dang Thi Thu Hoai (2017)

to other countries in Southeast Asia, Vietnam ranked first and third place regarding crude oil and gas, respectively. In Vietnam there are two national enterprises operating in the fuel sector: The Vietnam National Oil and Gas Group (Petrovietnam) and the Vietnam National Petroleum Group (Petrolimex). Supported by the Soviet Union, Petrovietnam started to explore and produce oil and gas in the North of Vietnam in 1961. From 1986 to 2013, the Vietnamese petroleum industry annually produced on average 16 million tonnes of crude oil and 7 billion m³ of gas. Regarding energy security, Petrovietnam achieved to meet 33.7%, 32.7% and 7.8% of the domestic demand for gasoline, diesel oil and fuel oil, respectively. From 2008 to 2015, Petrovietnam contributed on average 16-18% to the national GDP thereby underlining the importance of the fuel sector for the national economy. In general, Vietnam's oil and gas processing contributes to energy security, promotes industrialisation and modernisation and improves the competitiveness of Vietnam's oil and gas industry in the world. Therefore, the exports of crude oil play a crucial role in stabilising exchange rates, paying foreign debts and gaining foreign currency and investments needed for imports and international transactions. Nevertheless, the share of crude oil in the overall export value decreased from 26.41% in 2005 to 2.34% in 2015 due to a decline of production in large fields and the increasing domestic demand. Recently, there are mainly small fields of oil and gas discovered and exploration activities are time-consuming and costly, because they are conducted in off shore and deep-water areas.[12] Moreover, Vietnam is vulnerable to volatilities in global fuel prices, because it is nowadays a net importer of transportation fuel. As energy-deficient country, the production of biofuels might enable Vietnam to reduce the dependence on imports and to improve its trade balance.[13] That's why, it is interesting for the Vietnamese government to invest in alternative energy sources like bioenergy.

3.3 Bioenergy sector

Renewable energy, excluding large hydro power, is planned to cover 10% of Vietnam's domestic power demand in 2030.[14] As discussed in Chapter 3.1 Vietnam faces a continuously rising energy demand and a slow development of renewable energy. That's why, this goal seems to be rather ambitious. The promotion of renewable energy in Vietnam is further slowed down by influential energy enterprises lobbying for the existing energy system. For example, the current Environmental Protection Tax still includes only low taxes for coal and petroleum products and decision-makers perceive renewable energies as not constantly available and thus doubt that they might provide a stable energy supply.[15] The Vietnamese technology for producing biofuels also lacks behind foreign standards, because it is old. This makes biofuels often not competitive with conventional fossil fuels due to a high energy consumption and low productivity.[16] Therefore, it is crucial to promote technology transfer and to demonstrate decision makers that a well-established bioenergy industry reliably contributes to the country's energy security.

According to a study published by WWF in 2016, Vietnam's potential for onshore wind energy is moderate to good and for solar power very high. [17] There are also some support mechanisms for electricity generation from renewable energies like exceptions from duties, tax benefits and feed-in-tariffs. As a consequence, EVN is obliged to buy any electricity generated from renewable energy sources.[18] Moreover, Vietnam has

[12] Le et al. 2016
[13] Trinh and Le (2018)
[14] GIZ (2017)
[15] Neefjes. Koos; Dang Thi Thu Hoai (2017)
[16] World Energy Council (2016)
[17] WWF (2016)
[18] Vieweg et al. (2017)

significant potential for generating electricity from biomass and biogas sources.[19] Therefore, the cultivation of bioenergy crops on post-mining sites might be an option to promote Vietnam's bioenergy generation by giving decision makers a best-practice example.

The following chapters give an overview about the current situation of the bioenergy sector in Vietnam. Thereby, they focus on bioethanol, biogas, biodiesel and biomass and evaluate their overall potential as domestic energy sources.

3.3.1 Bioethanol

The demand for biofuels is increasing worldwide and was at 157 billion litres in 2021. It is estimated that it will reach 186 billion litres in 2026. In Asia, the demand will increase by 37.5% from 23.2 billion litres in 2021 to 31.9 billion litres in 2026 (see Figure 3). Due to domestic policies, growing liquid fuel demand and export-driven production, Asia will account for around 30% of the new production.[20] These numbers show the growing relevance of the biofuel sector in Asia but what is the status quo in Vietnam and how is it estimated to develop in the future?

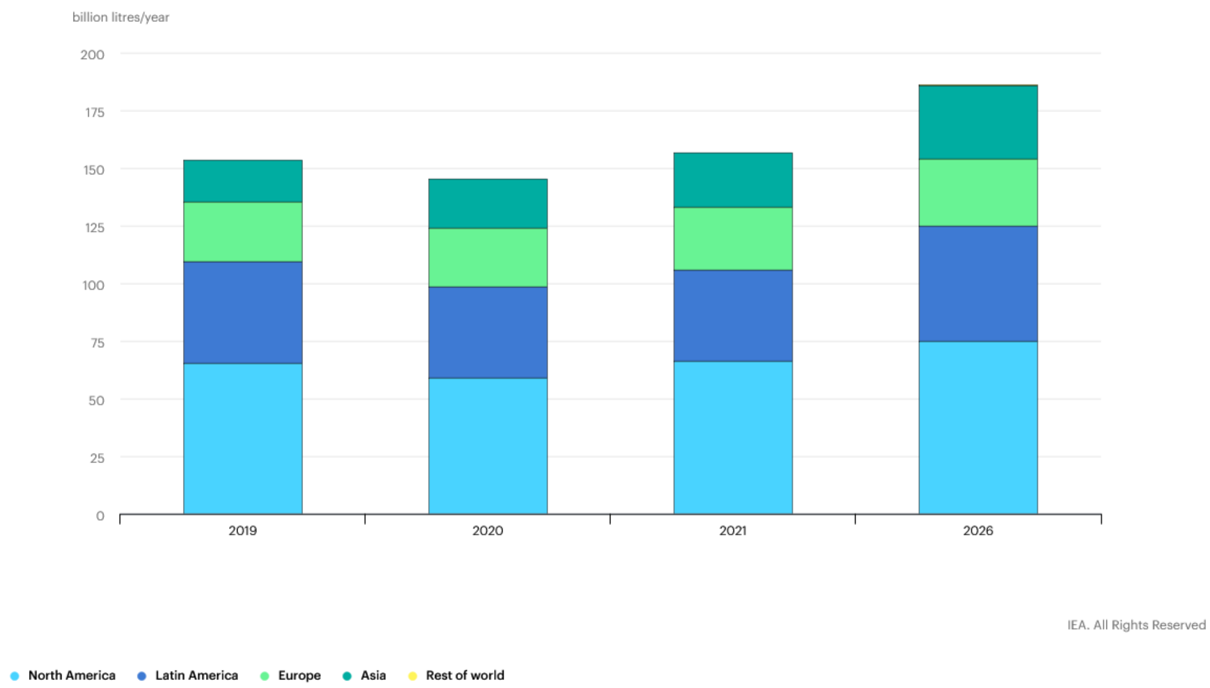

Figure 4: Global biofuel demand by region, 2019-2026 (IEA 2022a)

In Vietnam, the bioethanol industry is currently based on cassava as the only feedstock.[21] In 2019, Vietnam had 7 ethanol facilities with a total capacity of 612 million litres per year. However, 5 of them are currently out of use and only Ethanol Tung Lam in Dong Nai and Bioethanol Dai Tan in Quang Nam operate with a capacity of 72 and 125 million litres per year, respectively. The main reason is that ethanol manufacturers

[19] WWF (2016)
[20] IEA (2022b)
[21] UfU (2018b)

have to deal with an unstable supply of feedstock, because Chinas growing demand for cassava leads to an increasing export price, which is higher than the domestic purchase price. As a consequence, farmers rather sell their cassava on the Chinese than the domestic market.[22] In addition to that, ethanol facilities compete for cassava with starch and animal feed producers.[23] The negotiation of cassava offtake contracts between farmers and ethanol manufacturers and further advice for farmers on how to increase their productivity could be opportunities to ensure a stable supply of feedstock to the ethanol facilities in Vietnam.[24] Otherwise, the ethanol facilities will further rack up losses jeopardizing thousands of jobs and millions of dollars in investment.

Between 2013 and 2016, just 1.2% to 2.9% of the cassava harvest was used for producing bioethanol in Vietnam. The majority was exported. That's why, the cassava price mainly depended on the global market and not the domestic consumption. Even a growing ethanol demand due to further blending, will only lead to minor price increases of cassava in the future. So, the demand for bioethanol does currently not have a negative impact on food security in Vietnam.[25]

E5 gasoline is highly volatile, because fuel losses due to evaporation as well as transportation and storage costs are higher than those of conventional gasoline. That's why many biofuel sellers are not willing to provide consumers with biofuels.[26] In Vietnam, the 2 biggest fuel enterprises, Petrolimex and PVOil, both have different distribution strategies. Petrolimex has 7 blending stations with an overall capacity of 1.8 billion litres, whereas PVOil has 12 blending stations with an overall capacity of 1.67 billion litres. Thus, having many small capacity blending stations enables PVOil to respond quickly to the rising demand for E5 and to reduce losses and transportations costs.

In 2017, the Vietnamese Government announced Decision No. 255/TB-VPCP obliging gasoline traders to replace conventional gasoline like RON 92 with E5 nationwide since the beginning of 2018.[27] As a result, the share of E5 in the total gasoline consumption increased from 9% in 2017 to 40% (3.56 billion litres) in 2018 but decreased to 32% in 2020.[28]

The price is considered to be the most important factor regarding consumers' decision making. Through the excise tax, environmental protection tax and stabilisation fund, the Vietnamese Government wants to incentivize consumers to buy E5 gasoline. However, the current price difference between E5 and RON95 of around VND 1,400 to 1,600 per litre seems to be insufficient for consumers to prefer the first over the latter. So, the Vietnamese government needs to increase the price differences for example through import tariffs and CO2 taxes on fossil fuels.[29]

Many consumers are also not aware about the environmental benefits of biofuels and are afraid that E5 gasoline might damage their engines.[30] Therefore, the Vietnamese government has to improve consumers awareness on the good quality of biofuels for example through PR campaigns.

[22] Nghiem et al. (2021)
[23] Trinh and Le (2018)
[24] Nghiem et al. (2021)
[25] (FAO 2018)
[26] Trinh and Le (2018)
[27] Vietnam Government Office (2017)
[28] Nghiem et al. (2021)
[29] Nghiem et al. (2021)
[30] Trinh and Le (2018)

3.3.2 Biogas

Biogas is produced out of manure from animal husbandry. It is estimated that there are about 85 million tonnes of livestock waste discharged in Vietnam every year, which can be processed to more than 212 billion m³ of biogas.[31] Considering the current manure management practices, Vietnam had the potential to produce over 71,000 TJ of biogas per year in 2020. However, by improving the manure management practices the potential energy production could even rise to 120,000 TJ per year.

There is a lack of large-scale farms for animal husbandry in Vietnam. For example, smallholders provide 80% of pork and hold 78% of Vietnamese cattle farms.[32] In 2015, ca. 500,000 small-scale biogas digesters were installed in Vietnam with an average size of less than 10 m³.[33] Depending on the province, the costs of installation vary between $200-400.[34] Small-scale producers can use biogas digesters quite efficiently on their farm but do not benefit from economies of scale like large-scale biogas facilities. Many farmers also lack financial resources and information about biogas technology and need advice and technical support.[35] In addition to that, there is a lack of adequate manure transportation vehicles and some farmers report that they do not have enough space or animals to support a biogas digester on their farms. So, they tend to discharge the manure to the environment instead of fertilising their crops or producing energy while causing additional greenhouse gas emissions and environmental pollution.[36]

The efficiency of producing biogas depends, among others, on the optimal temperature, because the methane production is much higher at temperatures above 20 °C. In the summer, the tropical and sub-tropical climate in Vietnam with an average air temperature of 34 °C definitely favours the production of biogas. In mountainous regions, though, the biogas production might be lower in the winter, when the temperature is at 10 to 15 °C. Leaks due to broken digester caps and gas valves are an additional problem, because they might even increase greenhouse gas emissions and, thus, undermine environmental benefits. This is also the case, if the household produces more biogas than required and releases it into the atmosphere. In this case, farmers might also think about sharing a biogas digester to split the costs for construction and maintenance. In Vietnam, the optimal retention time of digesters should be at least 20 days but is often just between 1 and 20 days. In addition to that, farmers often use water contaminated with chemicals and a higher manure water ratio (1:8 - 1:20) than recommended (1:3). Thus, the fermentation process and the production of biogas are diminished.[37] Therefore, it is crucial that independent inspectors regularly examine the biogas digesters to ensure their functionality.

[31] Ho et al. (2015)
[32] Rubik et al. (2017)
[33] Ho et al. (2015)
[34] Cu et al. (2012)
[35] Ho et al. (2015)
[36] Cu et al. (2012)
[37] Cu et al. (2012)

3.3.3 Biodiesel

Biodiesel can be processed out of Jatropha oil. According to many experts, this is currently not economically feasible in Vietnam though, because the market price of biodiesel is too low. For example, 1 kilogram of jatropha seeds costs 3000 VND. To produce 1 litre of biodiesel you need 3 kilograms of jatropha seeds. However, the price for 1 litre of biodiesel is 10,0000 VND. So, the price roughly covers the costs for the seeds, 9000 VND; without any revenue.[38] Nevertheless, the Vietnamese Ministry of Agriculture and Rural Development wanted to expand the cultivation area to 500,000 ha by 2025 and promoted a project called "Research, development and use of products of jatropha curcas in Vietnam for the period 2008-2015 and vision to 2025". Consequently, companies like Revo Vietnam started full-scale Jatropha cultivation projects in Vietnam.[39]

In Vietnam, some biodiesel plants also use outdated filtration technologies resulting in low oil recovery rates and higher prices making the blending of biodiesel uneconomical.[40] Overall, the current conditions for producing biodiesel in Vietnam are not favourable. Therefore, the CPEP project concentrates on cultivating energy crops for the production of bioethanol and biogas.

3.3.4 Electricity generation through the combustion of biomass

There are currently no biomass power facilities from woodchips or other feedstock in Vietnam. Acacia wood can be co-fired in coal thermal power plants though. Therefore, in this chapter, the efficiency and competitiveness of firing acacia wood chips is compared with firing coal in thermal power facilities by using the levelized costs of energy (LCOE). The LCOE is a tool to calculate the cost per kWh of electricity generated. This indicator is commonly used for comparing the costs of different energy generation technologies over their economic life. The benefit of using LCOE is the inclusion of avoided emissions of CO2 for using a renewable technology.

In 2020, with a base scenario of $20 million of investment costs (465 billion VND), 9000 kW of net power generation, a capacity factor of 75%, a net efficiency of 20%, a fuel price of $32.7/ton (approximately 761,000 VND/ton) and an interest rate of 7%, the LCOE of biomass powered facilities combusting acacia wood were $0.0867/kwh. Consequently, producing 1 kwh of energy from acacia wood costs $0.0867. [41] This is more than the LCOE of ultra-supercritical ($0,0835), supercritical ($0,0809) and subcritical coal powered facilities ($0,0742). Consequently, biomass powered facilities are currently less efficient and competitive than coal powered facilities. However, increasing the Cost, Insurance, Freight (CIF) price of imported coal would raise the LCOE of coal-powered facilities making them less competitive than biomass powered facilities. Until 2030, the LCOE of ultra-supercritical, supercritical and subcritical coal powered facilities are expected to increase to $0,0871, $0,0848 and $0,0785, respectively, due to an increasing CIF price. The LCOE of biomass power facilities stays at $0,0867 because acacia wood is obtained from national supplies and its price is thus independent from the CIF price.[42] Therefore, the Vietnamese government could give incentives to invest in biomass-powered facilities and the cultivation of energy crops by increasing the import taxes of coal in the future. However, biomass powered facilities also have to compete with other renewable energy sources. For

[38] Trinh and Le (2018)
[39] Revo International (2022)
[40] World Energy Council (2016)
[41] Own calculation
[42] Green ID (2017)

example, the LCOEs of small hydropower facilities and ground-mounted solar panels are at \$0,0492 and \$0,0807, respectively.[43]

In summary, as long as the CIF price of imported coal does not increase biomass powered facilities are less efficient and competitive in generating electricity through the combustion of acacia wood than coal power facilities through the combustion of coal.

[43] Green ID (2017)

4. Cultivation of energy crops on former mining sites

In the CPEP project, the cultivation of energy crops on three different post-mining sites in Vietnam was tested from 2016 to 2018. The sites differ in terms of location, type of mining activities, climate conditions and combination of energy crops.[44] The key data of the test sites and the selected crops are presented in the following chapters.

4.1 Key data of the test site in Quang Ninh Province

In northern Vietnam in Quang Ninh, the test site has a total size of 15,000 m² and is situated on the waste rock dump Chinh Bac in the mine of Ha Tu in the city of Ha Long, which is part of Vietnam's largest hard coal mining area. The local climate is classified as humid subtropical with an average temperature of 23.7 °C and an annual precipitation of 1,882 millimetres. Between March and October, Quang Ninh is often the scene of extreme weather events like typhoons. The test site lies 260 m above sea but is entirely flat, because it is on the top plateau of the waste dump.

Due to little organic matter, soil fertility is rather low with a pH-value ranging from 5.2 to 5.8. Soil analysis detected heavy metals like As (Arsenic), Cd (Cadmium), Co (Cobalt), Cr (Chromium), Hg (Mercury), Mn (Manganese), Ni (Nickel), Pb (Lead) and Zn (Zinc). However, none of the heavy metal contents exceeded the maximum permitted amount for agricultural land.

During the first planting period in 2016, the test site was divided into six plots and both acacia hybrid and sweet sorghum was planted. The first is a fast growing tree which can be used for energy wood production and the latter is suitable for bioethanol production. Other energy crops which can be used for producing bioethanol like cassava or sugar cane were not considered on this test site, because they usually require better soil conditions and fertility. Further perennial wooden trees like the Chinese Wood-Oil Tree were planted in the second planting period to accelerate the development of the topsoil and because the yield of sweet sorghum was unexpectedly low showing that the test site is not suitable for agricultural production. Lastly, VA06 grass was planted on a slope nearby for erosion control and biomass production.[45]

4.2 Key data of the test site in Thai Nguyen Province

In the north of Vietnam in Thai Nguyen Province the test site is situated in an active mining area in Vietnam's largest tungsten mine, Nui Phao, in the Ha Thuong Commune in the Dai Tu District. It has a total size of 29,000 m² and lies 60 m above sea. The local climate is classified as humid subtropical with an average annual temperature of 23 °C and an average annual precipitation of 1,851 mm.

After mining activities were completed, the previously removed topsoil mixed with compost substrate was reapplied in a thickness of 50 centimetres on the test site. Underneath, skeletal material like gravel and crushed rock from the backfill of the mining activities can be found. By 2018, the thickness of the topsoil layer had decreased to an average of 35 centimetres due to slumping and slight surface erosion. In 2015, three plots were established on the test site namely 4,500 m² of acacia hybrid, 4,000 m² VA06 grass and 1,080 m² of sweet-sorghum. Accompanying spot testing of soil parameters and heavy metal contents of the test sites

[44] UfU (2018a)
[45] UfU (2018a)

indicate a very heterogeneous status regarding heavy metal contamination across the three established sites. Concentrations for As clearly exceeded threshold concentrations according to Vietnamese law under QCVN 03-MT:2015/BTNMT in all three plots. Exceeding of threshold values for Cu (Copper) were recorded for the VA06 grass site. All three sites exceeded threshold concentrations regarding Zn. If the control and measurement values for the impact pathway soil - plant are applied according to German law with regard to growth impairment and plant quality, there are suspicions of harmful effects on this impact pathway by As, Cr, Cu, Pb, Zn on all three sites, which must be evaluated. The pH value of the sites ranges from 4.3 to 6.3. Due to the mixing with compost manure the organic content is up to 1.77% to 1.99%.
In the following years there were three major planting seasons. Sweet sorghum was harvested three times. After the third harvest sweet sorghum was replaced by cassava, because it was affected by diseases and plagues. In the same time the perennial VA06 grass was cut four times. Also, the acacia hybrid trees stayed in the ground due to their perennial growth.[46] These are due for harvest after 5-6 years.

4.3 Key data of the test site in Lam Dong Province

In southern Vietnam, the test site is situated in the Central Highlands in Bao Lam district in the Lam Dong Province. The plantation has a total size of 20,000 m² and is on the area of the Tan Rai bauxite mine managed by VINACOMIN. In Bao Lam district, the climate is classified as tropical monsoon climate with an average annual temperature of 23 °C and an average annual precipitation of 3,370 mm. The test site lies 890 m above sea and is inclined about 9% from west to east.
Before the mining activities began, the topsoil was extracted and stored. It was applied again, after the mining activities were completed. Due to this procedure the original soil structure was destroyed. The accompanying soil analyses found heavy metals like As, Cd, Cu, Hg, Pb and Zn as well as a pH-value varying between 5.6 and 5.8. In two samples Zn and As even exceeded the maximum permitted amounts for agricultural land.
In Lam Dong annual crop species were preferred, because the test site is more suitable for short term agricultural production. The cultivation area was divided into five plots. Jatropha and sunflower were selected for the first planting period in 2016. Both can be used to produce biodiesel. In the second planting period in 2017, cassava, sweet sorghum, VA06 grass, acacia hybrid and hibiscus were added to the test plantation. Cassava and hibiscus can be used for producing bioethanol and biodiesel, respectively.[47]

[46] UfU (2018a)
[4747] UfU (2018a)

5. Bioenergy conversion and supply chains of selected crops in the CPEP project

This chapter deals with the different energy crops selected in the CPEP project and how they can be processed into bioenergy. The focus is on the conversion processes for the production of bioethanol from cassava as well as biogas from livestock manure and for the combustion of acacia wood. Even though these crops are found to be the most suitable, the cultivation of sweet sorghum, jatropha curcas, sunflower and Chinese wood-oil tree is shortly introduced as well to elaborate why these crops are not further considered by the CPEP project.

5.1 Selected crops for the production of bioethanol

Both cassava and sweet sorghum can be processed into bioethanol but why is cassava more suitable for the purposes of the CPEP project? This question is answered in the following chapters by comparing the yields of the different crops with each other.

5.1.1 Cassava (Manihot esculenta)

Cassava is a perennial crop in the family of Euphorbiaceae and native to South and Central America. Its starchy roots can be processed into dried chips, which are used for the production of bioethanol through fermentation. There are multiple advantages of producing cassava. Firstly, it is drought-tolerant and secondly it can be cultivated on soils with low fertility and harvested at any time of the year. Therefore, it is often the last crop in a rotation cycle. The roots have the highest starch content after 12 to 15 months but are getting more and more difficult to process over time, due to a higher degree of lignification.[48]
In 2019, Vietnam produced 10.2 million tonnes of cassava on 519,000 ha.[49] In 2014, it accounted for 3% of the country's total agricultural production value.[50] 77% and 22% of the cultivated cassava is distributed to starch companies and ethanol factories, respectively. The total value added in the starch distribution channel (US$150.45) is slightly lower than in the ethanol distribution channel (US$151,3). [51] Cassava is a labour-intensive crop requiring 260 man days per hectare. The average yield of cassava roots differs widely in the literature. One study states an average yield of 12.73 tonnes per hectare with a conversion ratio of 7 to 1 resulting in 1.78 tonnes of dried chips.[52] However, Xuan et al. (2019) report an average yield of 20 tonnes per hectare and a conversion ratio of approximately 2 to 1, which results in 10 tonnes of dried chip per hectare.[53] Another study even states an average yield of 35 tonnes per hectare.[54] In the CPEP project on the test site of the Nui Phao Thai Nguyen Tungsten Mine, the cassava yield was 24.92 tonnes per hectare. This means that in comparison with the literature, the cultivation of cassava on the test site has been rather successful.

[48] UfU (2018a)
[49] GSO (2021)
[50] FAO (2018)
[51] Xuan et al. (2019)
[52] CIAT (2019)
[53] Xuan et al. (2019)
[54] Trinh and Le (2018)

5.1.2 Sweet Sorghum (Sorghum bicolor)

As an annual poa plant sweet sorghum is part of the poacea family and grows up to 2.5 to 5 meters. It differs from grain sorghum through its rapidly growing juice rich sugary stalks. Due to its high sugar content, sweet sorghum can be processed into bioethanol through fermentation. Sweet sorghum is best cultivated in regions with 400 to 600 millimetres of annual precipitation but is able to recover completely after long lasting droughts. Furthermore, it is well adapted to soils with low fertility and can be harvested at least 2 times a year.[55]

Table 1: Sorghum yields on the test sites in comparison to cassava

Test Site	Quang Ninh Coal Mine	Lam Dong Bauxite Mine	Nui Phao Thai Nguyen Tungsten Mine			
Crop	Sweet Sorghum	Sweet Sorghum	Sweet Sorghum 1. harvest	Sweet Sorghum 2. harvest	Sweet Sorghum 3. harvest	Cassava cultivar KM 98
Cultivation	June 2016	June 2017	April 2016	August 2016	September 2016	March 2017
Harvest	November 2016	October 2017	August 2016	October 2016	March2017	January 2018
Trunk/Tube yield (t FM/ha)	**16.00**	**9.80**	**52.57**	**27.37**	**5.70**	**24.92**
Fermentable sugar/starch content (% on FM trunk/tube basis)	4.99	1.37	4.39	10.01	25.26	20.04
Fermentable sugar/starch (t/ha)	1.35	0.27	**2.31**	**2.74**	**1.44**	**5.00**
Ethanol 100 % wt. (t/ha)	0.44	0.089	**0.76**	**0.90**	**0.47**	**1.93**

Table 1 summarises the sorghum yields on the different test spots of the CPEP project and compares them with the cassava yield at the Nui Phao Thai Nguyen Tungsten Mine. Sweet sorghum was relatively prone to disease and plagues in wet climate on the testing spot in Nui Phao. Every new harvest the fresh matter trunk yield decreased from 53 tonnes per hectare in August 2016, to 27 tonnes per hectare in October 2016 and to

[55] UfU (2018a)

6 tonnes per hectare in March 2017. In Lam Dong, the fresh matter trunk yield was on average even lower with 10 tonnes per hectare in October 2017. Sorghum seems to be better adapted to dry climate, because there were no diseases or plagues detected in the Quang Ninh Province. However, the fresh matter trunk yield was also rather low with 16 tonnes per hectare. Moreover, the input costs for fertilisers and irrigation to generate good growth of sweet sorghum are very high in relation to the output and in comparison to other crops like cassava.[56] Even though the fresh matter yield of cassava tubes in Nui Phao was with 25 tonnes per hectare lower than the average sorghum yield, its fermentable sugar content of 5 tonnes per hectare was much higher than those of sorghum trunks ranging from 1.4 to 2.7 tonnes per hectare. In Nui Phao, regarding sorghum and cassava, the conversion factor of sugar to ethanol is 0.33and 0.39, respectively. This results in an ethanol production of 0.5 to 0.9 tonnes per hectare from sorghum and 1.9 tonnes per hectare from cassava. On behalf of the CPEP project, scientists from the Hanoi University of Science and Technology evaluated the energy yield of fresh sweet sorghum cultivated on the test spot in Nui Phao. They found an ethanol yield of 20 litres per tonne. In comparison, one tonne of fresh cassava roots can be processed into 174 litres of ethanol. [57]Overall, cassava is more suitable than sweet sorghum for producing ethanol in the context of the CPEP project. Therefore, sweet sorghum has not been further considered.

5.1.3 Conversion processes for the production of bioethanol

In Vietnam, the production of bioethanol is mainly based on cassava and includes farming, chips processing, ethanol production, ethanol distribution and blending, and ethanol use. After being harvested, the cassava roots are chopped into small pieces and laid down on the floor to be sun-dried. Most small-scale farmers in Vietnam use simple hand-held chipping knifes, because the amount of cassava produced is not enough to afford bigger chipping machines. Afterwards, the cassava chips are delivered to the ethanol facilities, where the ethanol production process consists of four main steps: milling, liquefaction, saccharification and fermentation and distillation. At first, the dried cassava chips are milled to make them physically suitable for the following steps. This includes removing impurities like metals, sand and soil. Then, the cassava starch is cooked and exposed to α-amylase to liquefy the slurry. Next, the slurry is cooled down to 32 °C and glucoamylase is added to produce glucose, which is directly processed into ethanol by yeast. Lastly, the fermentation broth is distilled and dehydrated to concentrate the ethanol to 99.5%. On average, the conversion ratio of fresh roots to dried chips is 2.5 kilograms per kilogram and of dried chips to ethanol 2.3 kilograms per litre. This means that 1 tonne of fresh cassava can be processed into 174 litres of ethanol. [58] In the CPEP Project, the yield of fresh cassava was 24.92 tonnes per hectare resulting in 1.9 tonnes of ethanol (see Table 1). Regarding the average conversion ratio, 24.92 tonnes per hectare of fresh cassava can be processed into 4336 litres (3.4 tonnes) of ethanol. Consequently, the ethanol production from the cassava crops on the test sites of the CPEP Project is less than average.

As by-products dried distillers' grains are sold for animal forage, biogas is used as energy and CO_2 is collected to be sold. After being sold, trucks deliver bioethanol to blending stations, where it is blended with conventional gasoline.[59] In Vietnam, 7 enterprises are currently able to produce E5 gasoline.[60]

[56] UfU (2018a)
[57] HUST (2016)
[58] FAO (2018)
[59] FAO (2018)
[60] Nghiem et al. (2021)

Normally, cassava roots are used for processing but recent studies also identified methods to obtain bioethanol from agricultural residues like cassava stems[61] and waste pulps from starch-producing industries.[62] If this process becomes operational and cost-efficient, it might additionally contribute to the reduction of greenhouse gas emissions and promote green energy consumption in Vietnam. Moreover, using agricultural residues and waste pulps for ethanol production prevents land-use changes and, thus, avoids food insecurity and deforestation.

5.2 Selected crop for the production of biogas

In the CPEP project, VA06 grass is the only crop considered for producing biogas. Therefore, this chapter summarises the yields of the VA06 grass on the test sites and describes the conversion processes to produce biogas.

5.2.1 VA06 Grass (Pennisetum purpureum)

VA06 grass is a fast growing grass, which is used for erosion protection and renaturation, because its 50 to 60 centimetres long deep root system makes it drought-tolerant. VA06 grass can be cut up to 7 times a year but the cultures should be replaced after 5-6 years. Nevertheless, the use of the produced stem for recultivation is definitely a cost advantage.[63]VA06 grass is especially cultivated to produce silage for animal husbandry. The resulting manure can then be processed into biogas. The methane content in biogas from VA06 grass is 53% and its yield is about 122 litres per kilogram of dry matter.[64]
VA06 grass reaches heights up to 7 meters. In the CPEP Project on the test site in Thai Nguyen Province, it grew up to 5 meters during the rainy season (see Figure 1) and up to 4 meters during the dry season within 155 days. On sandy soils in three south central coastal provinces of Vietnam, the average dry matter yields are 26.4, 39.4 and 39 tonnes per hectare and year.[65] However, in mountainous regions in the northwest of Vietnam, it is 66.65 tonnes with a regeneration intensity of 1.48 tonnes per hectare and day, respectively.[66] In comparison, the fresh matter yields on the different test plots of the CPEP project were 164.49, 195.05 and 212.88 tonnes per hectare and year. With regard to the average dry matter content of 15.5%,[67] the dry matter yields are 25.50, 30.23 and 33 tonnes per hectare and year, respectively. Therefore, the dry matter yields of VA06 grass cultivated within the CPEP project are comparable with Vietnam's south central coastal provinces but are less than in the mountainous regions in the northwest. Considering the non-optimal soil qualities on the test sites, the cultivation is still rather successful.

[61] Phan et al. (2019); Tanaka et al. (2019)
[62] Icalina et al. (2018)
[63] UfU (2018a)
[64] Sawasdee and Pisutpaisal (2014)
[65] Mann et al. (2015)
[66] Mai et al. (2014)
[67] Vietnam Belgium Dairy Project (2009)

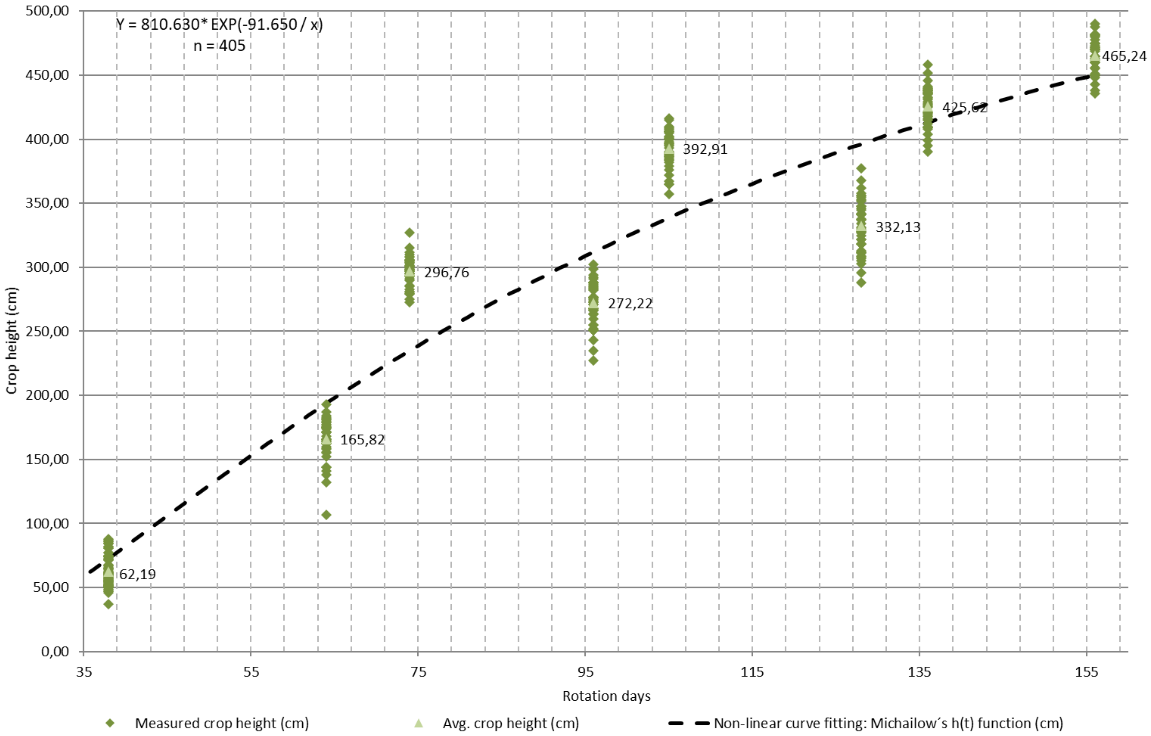

Figure 5: Measured, average and estimated height of VA06 grass in the rainy season

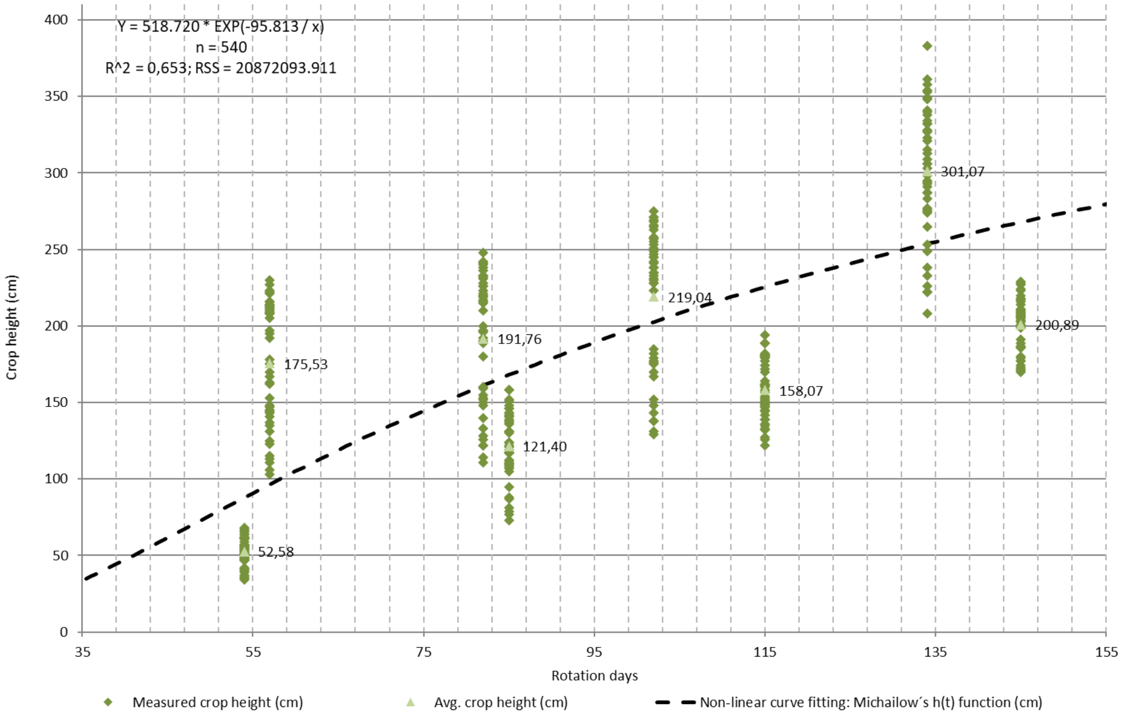

Figure 6: Measured, average and estimated height of VA06 grass in the dry season

5.2.2 Conversion processes for the production of biogas

VA06 grass is used as forage for animal husbandry. Digesters can process the resulting manure into biogas, which serves as energy source for lightning, cooking and water heating on the household level. However, the amount of biogas produced by small-scale digesters is often only sufficient for cooking and is not sold to third parties. According to the Biogas Program for the Animal Husbandry Sector in Vietnam, each kilogram of fresh cow manure can be processed into approximately 0.024 m³ of biogas.[68] In Vietnam, farmers mainly use pig manure as feedstock.[69] Bio-waste, food residues and human faeces are possible alternative inputs, too.[70] As a consequence, possible deforestation is curbed by reducing peoples' dependency on firewood. [71] Another by-product of fermentation is the digestate, which can be used as fertiliser. Therefore, the production of biogas is especially suitable for farmers in remote areas with limited access to chemical fertilisers and electricity.[72] Before applying the digestate to the field, it must be stored in tanks, because the anaerobic digestion process continues. The additional amount of biogas produced during the storage period is then recovered.[73]

On the one hand, small-scale digesters give local farmers the opportunity to add value to their waste and reduce their dependency on fossil fuels by producing renewable energy.[74] For example, estimations show that biogas digesters reduce the annual energy costs by $120-150 per farm[75]. On the other hand, they have positive impacts on the environment and public health by minimizing greenhouse gas emissions and the disposal of manure, which might otherwise contaminate air, soil and water sources with human pathogenic organisms.[76] At the industrial level, biogas is mainly used for own consumption and replaces gasoline and coal to produce heat for distillation or drying. The surplus is usually burned or discharged into the environment.[77]

5.3 Selected crops for the production of biodiesel

In theory, biodiesel can be processed out of vegetable oils from jatropha, sunflower and Chinese wood oil tree. All these plants have been considered as potential energy crops in the CPEP project. The following chapter shortly summarizes their advantages and disadvantages to show why the production of biodiesel was excluded within the CPEP project.

5.3.1 Jatropha curcas

Jatropha curcas is a succulent shrub and part of the Euphorbiaceae family. It reaches heights up to 8 meters, is cultivated in sub-tropical regions worldwide and can be used to produce biodiesel through transesterification. Its deep root system enables jatropha to be drought tolerant and suitable for erosion control. Jatropha was originally chosen, because mine machinery can run on jatropha oil as biodiesel without

[68] UfU (2018b)
[69] FAO (2018)
[70] UfU (2018a)
[71] Cu et al. (2012)
[72] Ho et al. (2015)
[73] FAO (2018)
[74] UfU (2018a)
[75] Cu et al. (2012)
[76] Roubik et al. (2017)
[77] FAO (2018)

further processing.[78] Another advantage is that jatropha is a non-edible crop. So, the food versus fuel controversy caused by using edible plant oils for biodiesel production is avoided [79] as long as the crop is cultivated on marginal lands not suitable for agricultural production like post-mining sites.
Jatropha seeds have an oil content of over 30% and 10 tonnes of seeds can be harvested from 1 hectare of intensive jatropha cultivation resulting in 3 tonnes of high quality biodiesel equivalent to fossil diesel.[80] However, the climate in the northern part of Vietnam does not favour the cultivation of jatropha and in the southern part on the test site in Lam Dong just 11% of the jatropha plants developed fruits. The yields are simply too low to be competitive. Therefore, it has been decided that jatropha is not a suitable option for the recultivation of former mining sites in Vietnam.[81]

5.3.2 Sunflower (Helianthus annuus L.)

Sunflower (Helianthus anuus L.) is a cold-tolerant erect herb ranging from less than 1 to 3.5 meters and can be used to produce biodiesel through transesterification. Even though it is originally from North America, it is now cultivated worldwide from the temperate zones to the tropics. Sunflower oil is mainly used in food production but the crop itself is also recently fed to cows.[82]
Sunflower can be potentially grown as energy crop in Vietnam, because it is suitable for the local climate. In addition to that, its root system supports soil loosening and a better aeration. Nevertheless, sunflower could not be cultivated successfully on the test site in Lam Dong. The low water storage capacity of the soil and a germination rate of just about 3% led to slow growth and root development. As a result, the output of 4.6 kilogram of sunflower seeds was less than the seeds used for cultivation.[83] Future studies need to find more suitable spots for cultivating sunflowers in Vietnam.

5.3.3 Chinese Wood-Oil Tree (Vernicia montana)

Chinese wood-oil tree is an evergreen perennial tree and part of the Euphorbiaceae family. It is originally from South-East Asia and grows up to 15 meters. Its fruits contain three oleaginous cores, which are not edible, because the tung oil is poisonous, but can be used to produce biodiesel.[84]
As a native species, Chinese wood-oil tree is well known by local residents and suitable for recultivation in Quang Ninh. Due to its slow growth, the planning needs to be long-term. For example, in Malawi annual yields of air-dry high quality seeds gradually increase from 0.28 tonnes per hectare in 3-6-year-old plantations to 2.2 tonnes per hectare in 11-14-year-old plantations and 3.0 tonnes per hectare in 20-years-old plantations.[85] However, it is not a common species in the nurseries anymore. Therefore, seeds are available only in small amounts. In addition to that, only female Chinese wood-oil trees develop seeds, which further impedes the selection on seedlings.[86] That's why, this species has not been further considered in the CPEP Project.

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[78] Official Letter 3435/BNN-TCLN of the Ministry of Agriculture and Rural Development on the report on the research and development situation of Jatropha curcas L. in Vietnam
[79] Norjannah et al. (2016)
[80] Official Letter 3435/BNN-TCLN of the Ministry of Agriculture and Rural Development on the report on the research and development situation of Jatropha curcas L. in Vietnam
[81] UfU (2018a)
[82] UfU (2018a)
[83] UfU (2018a)
[84] UfU (2018a)
[85] Tropical Plants Database, Ken Fern (2022)
[86] UfU (2018a)

5.3.4 Conversion process for the production of biodiesel

There are currently three different production processes to generate biodiesel through transesterification and esterification. The non-catalysed, the chemical-catalysed and the enzyme-catalysed reaction. In the non-catalysed reaction methanol or ethanol are used to produce biodiesel through transesterification. Even though this production process is fast, has a high reaction rate, generates no waste and makes it easy to separate the output, it is expensive and energy-intensive requiring high temperatures and pressure. In the chemical-catalysed reaction acid or alkali catalysts are used in liquid form (homogenous-catalysed reaction) or in solid form (heterogeneous-catalysed reaction). For example, the homogenous-catalysed reaction has been previously used to produce biodiesel from non-edible crops like jatropha. However, this production process consumes a high amount of energy and entails further disadvantages like the costly recovery and purification of catalysts and glycerol and the subsequent wastewater treatment. [87] These are reasons, why the biodiesel production from jatropha is not further considered in the CPEP project. For the enzyme-catalysed reaction vegetable oil, an acyl acceptor like an alcohol and an enzyme called lipase as catalyst are needed to generate biodiesel. Even though this process has many advantages like no generation of wastewater, low alcohol to oil ratio, completely catalysis of free fatty acids and a high output quality, it is currently very cost-intensive. That’s why, further improvements of the production processes are needed, before the production of biodiesel can be further considered by the CPEP project.

5.4 Selected crop for the combustion of biomass

5.4.1 Acacia hybrid

Acacia hybrid grows in Southeast Asia and is a hybrid of acacia mangium and acacia auriculiformis. It is a fast growing perennial tree reaching 8 to 10 meters in 2 years. Therefore, it generates higher average yields than acacia mangium and acacia auriculiformis and can already be harvested after 5 instead of 7 years. Acacia hybrid can be cultivated in short rotation forestry and used as combusting material for energy production. In Vietnam, the acceptance for acacia hybrid is pretty high, because it is well-known and the most successful tree used for recultivation on waste rock dumps. To date, many different species have been tested in Quang Ninh Province since 2007.[88]

In southern Vietnam in the second rotation, acacia hybrid grows on average 23 m^3 per hectare and year, which generally exceeds the first rotation. With 18 m^3 per hectare and year the growth is slower in northern Vietnam.[89] In Nui Phao and Quang Ninh, acacia shows to be a well suitable energy source and recultivation option, because it does not require any further maintenance after planting and still grows steady and fast. As part of the legume family it also fixes nitrogen in the soil. By adding other species to the initial acacia plantations, it is later on a perfect fit for agroforestry practices.[90] Within the follow-up project, the acacia trees will be harvested to precisely assess their quality and yield.

[87] Norjannah et al. (2016)
[88] UfU (2018a)
[89] Harwood and Nambiar (2014)
[90] UfU (2018a)

5.4.2 Conversion processes for the combustion of biomass

Through drying and grinding wood chips, the wood of acacia hybrid can be easily used as combusting material for energy production in biomass or coal thermal power facilities, which mostly use direct-fired combustion systems.[91] They burn biomass directly to produce high-pressure steam that drives a turbine generator to make electricity. In some biomass industries, the extracted or spent steam from the power facility is also used for manufacturing processes or to heat buildings. These combined heat and power systems greatly increase overall energy efficiency to approximately 80%, from the standard biomass electricity-only systems with efficiencies of approximately 20%. Direct combustion in a grate boiler followed by the steam turbine to generate electricity is well developed and proven for various fuels and available at relative low investment costs in Asia. Therefore, the grate combustion technology is considered for combustion of acacia woodchip. Waste combustion is another energy generation option, which is especially cost-efficient if the waste would otherwise incur costs for disposal.[92]

[91] UfU (2018a)
[92] Nguyen et al. (2019)

6. Potential utilisation scenarios

In this chapter, the potential utilisation scenarios for the energy crops from the different test sites are introduced. Scenario 1 is about the production of bioethanol from cassava cultivated on the test site in Thai Nguyen Province. Scenario 2 deals with VA06 grass planted on the same test site as forage for livestock to use the resulting manure for the production of biogas. Lastly, scenario 3 discusses the combustion of acacia wood from the test site in Quang Ninh Province.

6.1 Scenario 1: Utilisation of cassava in Thai Nguyen Province

Both sweet sorghum and cassava can be processed into bioethanol as discussed in Chapter 5.1.2. However, the first was replaced by the latter on the test site in Thai Nguyen Province, because in comparison to sweet sorghum, cassava was less prone to diseases and the fermentable starch content necessary for producing bioethanol was twice as high. Furthermore, the domestic bioethanol industry is specified in using cassava as the only feedstock. Therefore, scenario 1 deals with the production of bioethanol from cassava cultivated on the test site in Thai Nguyen Province.

After being harvested, cassava can be manually sliced and sun-dried nearby the cultivation area before being delivered as dried chips by 40 t trucks to the bioethanol facility. Either cassava is delivered directly to the bioethanol facilities or it is exported from the next port.[93] Even though there is currently no bioethanol facility in operation in Northern Vietnam, one is under construction in Phu Tho Province at a distance of 290 km from the test site.[94] This bioethanol facility is taken into account as a potential conversion facility, because trucks can directly provide it with dried cassava chips from the test site in Thai Nguyen Province. As discussed in Chapter 5.1.3, the dried chips are then processed into bioethanol through milling, liquefaction, saccharification and fermentation and distillation and dehydration. In the CPEP Project, one hectare of cassava could be processed into 1.9 tonnes of bioethanol, which is 1.5 tonnes less than on average. Other by-products are dried stillage and distiller grains sold for producing animal feed, biogas used for energy production and liquid CO2 sold to fire protection or beverage factories, where it is used for fire extinguishers or beverage bottles, respectively. The produced bioethanol is then purchased by oil companies and delivered to the blending stations. Due to Decision No. 255/TB-VPCP by the Vietnamese Government gasoline traders are obliged to replace conventional gasoline like RON 92 with E5 as mentioned in Chapter 3.3.1. Therefore, petroleum distribution companies installed several blending stations across Vietnam. There are three different blending methods namely the in-tank recirculation, the static mixer and the in line blend. The first two use tanks for blending while the latter directly blends gasoline and bioethanol in line. Most of the petroleum distribution companies like Petrolimex and PVOil use the in line blend method, before the gasoline is transported by trucks or ships to the gasoline stations.[95] There it is finally sold as E5 gasoline to the end consumer.

After the first phase of the CPEP project was completed, the cultivation of cassava was switched from the test site in the Thai Nguyen Province to the test site in the Lam Dong Province. Therefore, future studies within the project will concentrate on the utilisation opportunities of cassava cultivated on the test site in the Lam Dong Province.

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93 Nguyen (2018)
94 UfU (2018b)
95 Nguyen (2018)

6.2 Scenario 2: Utilisation of VA06 grass in Thai Nguyen Province

As described in Chapter 5.2.2, VA06 grass can be used by local farmers as forage for livestock in the Thai Nguyen Province. The resulting manure can then be processed into biogas by small scale digesters.
For scenario 2, a small scale digester was installed on a farm close to the test site and serves as a potential conversion facility of livestock manure. After being harvested, the VA06 grass is transported directly from the test site to the farm, where it is used as forage for livestock. The small scale digester is directly located next to the stables and is fed by manure to produce biogas through anaerobic digestion in the forms of methane (CH_4) and carbon dioxide (CO_2). The first is burned on-site in biogas stoves or used in small generators to produce heat or power, respectively. As co-product the liquid digestate is rich in organic compounds and mineral nutrients and can thus be used as fertiliser. The digestate must be stored appropriately in the tank, before being applied to the fields, because the anaerobic digestion process continues to produce biogas. In Vietnam, the additional amount of biogas can be further recovered since the digestate is stored in closed tanks. [96] If the biogas digester produces more biogas than necessary for household consumption, the additional biogas can be shared with farmers nearby. In that case, farmers might also think about sharing a biogas digester to split the costs for construction and maintenance.
Scenario 2 has multiple advantages. Firstly, the costs and greenhouse gas emissions for transportation are rather low, because the VA06 grass is cultivated nearby and the biogas and digestate can be used directly on the farm. Secondly, farmers in remote areas become less dependent on electricity, fossil fuels, firewood and chemical fertilisers and get the opportunity to add value to their waste. As a consequence, deforestation and environmental damages are reduced, because farmers do not need to chop firewood or to dispose the manure into the environment. However, farmers need a continuous water supply to ensure a high water content in the digester.

6.3 Scenario 3: Utilisation of acacia wood from the Quang Ninh Province

Within the CPEP project, acacia hybrid is successfully cultivated on a post-mining site in the Quang Ninh Province. Therefore, this chapter evaluates the possible utilisation of acacia wood cultivated on the test site. As described in Chapter 5.4.2, acacia wood can be co-fired by coal thermal power facilities to generate electricity. The Cam Pha coal power facility, owned by VINACOMIN, is just 27 kilometres away from the test site and can produce energy by combusting acacia wood with a circulating fluidised bed boiler.[97] So after the harvest, the acacia wood cultivated on the test site can be directly transported to the Cam Pha coal power facility. The short distance between the test site and the coal power facility results in low costs and greenhouse gas emissions caused by transportation.
As evaluated in Chapter 3.3.4, the combustion of acacia wood in coal thermal power facilities is currently less efficient than the combustion of coal, because the costs per kWh for generating electricity through combusting acacia wood are higher than for combusting coal. Therefore, electricity producers like the Cam Pha coal power facility will probably prefer coal to acacia wood for electricity generation. Moreover, there are currently no biomass power facilities from woodchips or other feedstock in Vietnam. As an alternative, the acacia wood cultivated on the test site can be sold to households nearby for firing.

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[96] UfU (2018b)
[97] Truong (2015)

Overall, the idea of co-firing acacia wood in coal thermal power facilities will be not further elaborated in this project, because it generates less environmental benefits in comparison to the production of bioethanol by cultivating and processing cassava. Therefore, future studies need to assess how the co-firing of acacia wood in coal thermal power facilities or the development of biomass power facilities might decrease Vietnams greenhouse gas emissions and dependency on fossil fuels.

7. Potential climate effects of cassava-based bioethanol use in Vietnam

As the first utilisation scenario resulted in being the most promising scenario from an agricultural and economic perspective, this scenario was chosen for further investigation of its effects on the climate. Its potential GHG emissions and savings were calculated in comparison to their reference fossil fuel which, in the case of bioethanol (E5), would be conventional RON92 gasoline.

7.1 Projected greenhouse gas emissions and savings from the cassava-bioethanol scenario

7.1.1 Methodological framework

There is currently no bioethanol factory in operation in Northern Vietnam. However, there is a bioethanol factory under construction in the Phu Tho province which is at a distance of approximately 290 km from the pilot site. Therefore, it was taken into account as potential conversion facility for the hypothetical scenario. The energy production chain for the scenario is as follows: Cultivation of cassava on the pilot site in Thai Nguyen Province, use of cassava as ethanol feedstock in the ethanol factory of Phu Tho and use of ethanol for E5 gasoline blending.

For the evaluation of potential GHG emissions from the scenario, the GHG emissions were calculated using the Lifecycle Assessment (LCA) approach. For the cassava-based ethanol production, the stages of the value chain included in the LCA (system boundaries) are land use change; cassava cultivation; chipping; feedstock production; transformation and delivery to the ethanol plant; biomass processing into biofuels; and biofuel transportation, storage and distribution. The GHG LCA of bioenergy allows the identification of how the different steps contribute to the total GHG emissions. Figure 7 shows the different steps of the bioenergy production chain and its potential GHG emission sources. In the last step, the bioethanol (E5) is compared with the reference fossil fuel (RON95).

The three GHGs considered in the LCA are CO_2, CH_4, and N_2O. To make them comparable, they were converted into CO_2 equivalents (CO_2eq) using the following Global Warming Potential (GWP) factors (IPCC NGGIP Emissions Factors Database):

$GWP_{CO2\ fossil} = 1$
$GWP_{CO2\ biogenic} = 1$
$GWP_{CH4\ fossil} = 25$
$GWP_{CH4\ biogenic} = 25$
$GWP_{N2O} = 298$

The GHG emissions from ethanol production were calculated according to the guidelines from Bio-Grace and the European Commission as follows:

Emissions data from the cultivation process (e.g. yields, fertiliser) + emissions data for conversion (e.g. heating values, emission factors) = GHG emissions (incl. direct and indirect emissions)

Whereas direct emissions occur during the use of materials or fuels (e.g. combustion of fossil fuels), indirect emissions occur during the production of materials or fuels (e.g. production of biofuel). For the calculations, the Bio-Grace calculation tool was used.[98]

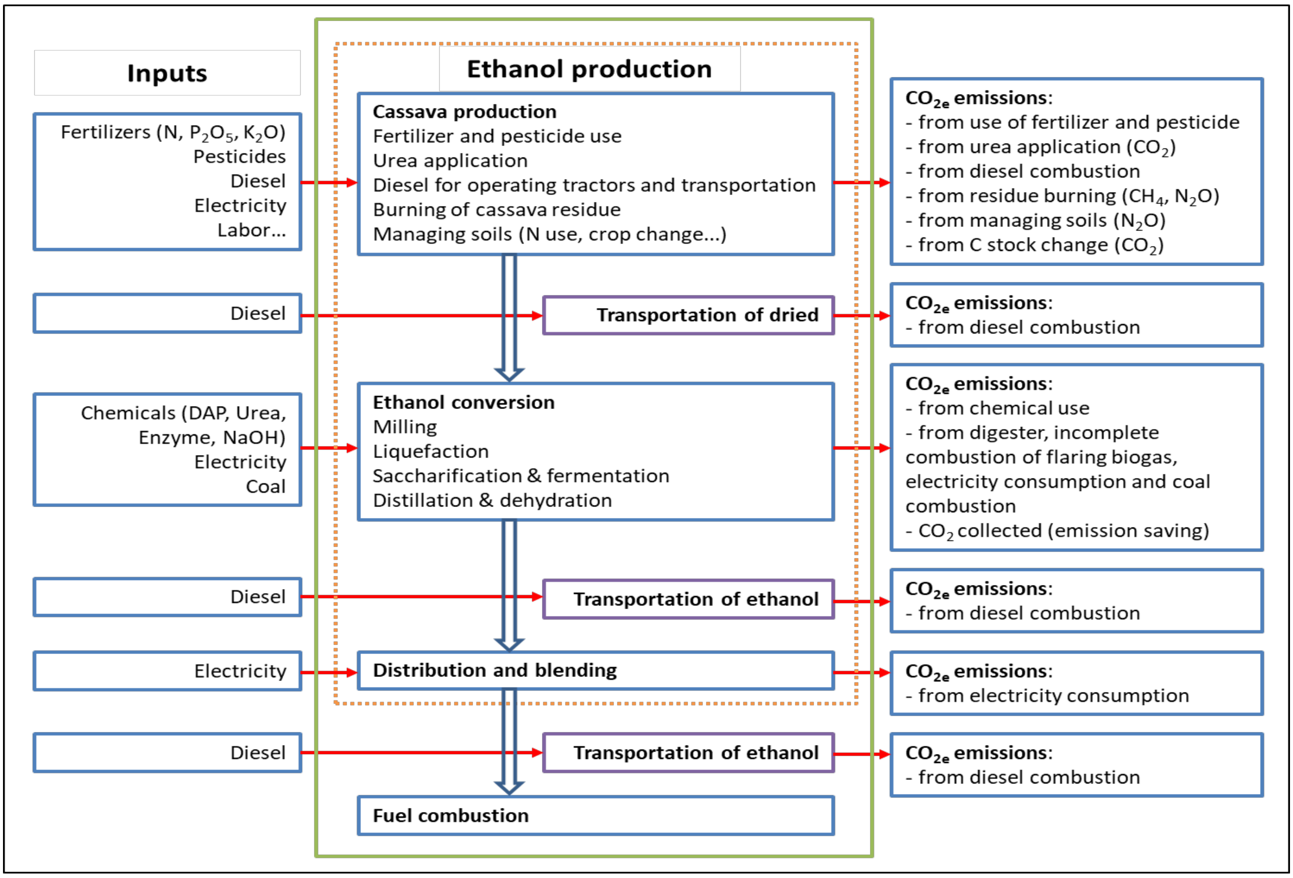

Figure 7: LCA steps of ethanol production and utilisation (system boundaries for the LCA)

7.1.2 Description of input data

Based on the cultivation data from the CPEP pilot cultivation and secondary data from previous studies (Le et al. 2013, Nguyen et al. 2018 and MONRE 2010) the emission sources from all ethanol production steps were identified and are listed in Table 2.

Due to the fact that the cultivation site was part of a tungsten mine that was neither covered by natural vegetation nor under agricultural use, LUC from mining to cultivation is not a source of GHG emissions in this scenario. Through the application of a new soil layer and potential carbon sequestration from crop cultivation it is even expectable that LUC contributes to light emission savings.

Regarding the cassava cultivation phase, cassava was planted on an area of 1,080 m^2. Prior to the planting, the soil was prepared by weeds cleaning and loosening the soil. Then, the soil was fertilised with manure, urea, lime and NPK 10-6-4.

[98] See https://www.biograce.net/

After the harvest, cassava is manually sliced and dried in the sun. Then, it is delivered to the ethanol plant in form of dried chips (final water content is on average 14 %). The conversion ratio of fresh root to dried chips is approximately 2.5 kg/kg (see also 3.3.1). There are two ways of feedstock delivery: 1) Either cassava is transported from cultivation areas to the plants; or 2) Cassava is transported from the next main exporting port to the plant. The transportation occurs by 40 t truck (full load). For round trips, diesel consumption for the 40 t trucks is on average 0.28 l/km.[99]

Due to the fact that the Phu Tho ethanol plant is currently not in operation, the average technical data provided by three operating Vietnamese ethanol plants is used for the conversion phase. There are four sub-processes to convert dried chips to ethanol: 1) milling, 2) liquefaction, 3) saccharification and fermentation, as well as 4) distillation and dehydration. Besides ethanol, by-products include dried distillers' grains sold for animal feed production, biogas used as supplemental energy and CO2 collected for sale. The conversion ratio of dried chips to ethanol is on average 2.3 kg/l.[100] Total GHG emissions from the ethanol processing phase are 1,100 g CO2eq/kg ethanol, of which a major share derives from burning solid fuels for steam production (using for slurry preparation, liquefaction, fermentation, distillation and dehydration) (see Table 2). The GHG emissions from the ethanol plants are partly balanced by the amounts of biogas used for Combined Heat and Power (CHP) generation and the allocation of co-products like dry stillage. Stillage is precipitated, centrifuged, dried (using biogas) and, then, sold for cattle feeding.[101] Liquid CO2 is another co-product, but it is not taken into account here, because of non-available data on electricity used for CO2 liquidation. Furthermore, the liquid CO2 collected from ethanol plants is sold to fire protection facilities or beverage factories, where it is loaded into fire extinguishers or beverage bottles, respectively. Therefore, this collected CO2 still causes GHG emissions indirectly.

The produced ethanol is sold to oil companies and delivered to blending stations by 30 m^3 trucks. For round trips, diesel consumption for the 30 m^3 trucks is on average 0.28 l/km. At the blending stations, three methods can be used: 1) in-tank recirculation; 2) static mixer; and 3) in line blend. The first two methods require tanks for handling the ethanol fuel, while in the "in-line blend" method, gasoline and ethanol are blended directly in line before being transferred by truck and ship to the gasoline stations. Therefore, most of the petroleum distribution companies choose the "in-line blend" method and several blending systems have been installed so far across the country.[102]

[99] Nguyen et al. (2018)
[100] Nguyen et al (2018)
[101] Nguyen et al (2018)
[102] Nguyen et al. (2018)

Table 2: LCA input data for cassava-based ethanol production

Land use change		
Land use change (LUC)	-0.02	kg CO_2eq / ha*a
Cultivation		
Yield		
Cassava	17.5	t/ha*a
Water content	60.3	%
harvest residue	47.1	t/ha*a
Fertiliser & pesticides		
Urea	75	kg N / ha*a
manure	39.2	kg N / ha*a
P2O5-Fertiliser	225	kg P_2O_5 / ha*a
K2O-Fertiliser	50	kg K_2O / ha*a
CaO-Fertiliser (kg CaCO3)	600	kg $CaCO_3$ / ha*a
Pesticides	0.00	kg / ha*a
Seeds		
Cassava cuttings	1111.1	kg / ha*a
Energy		
Diesel	22.5	l / ha*a
Emissions from diesel usage (agriculture)		
Electricity consumption (for irrigation)	45.0	kWh / ha*a
Electricity mix	Electricity mix Viet Nam	
Transport of cassava roots		
NO Transport losses	0.000	kg / kg cassava
Distance	10.0	km
Transport vehicle	Truck (40 t) for dry products	
Fuel	Diesel	
Chipping(pieces by hand)		
Yield	0.400	kg chips / kg cassava
Transport of cassava chips		
NO Transport losses	1	kg / kg cassava chips
Distance	289.0	km
Transport vehicle	Truck (40 t) for dry products	
Fuel	Diesel	
Processing - ethanol plant		
Ethanol	0.353	kg ethanol / kg cassava chips
Co-products		
Stillage cake	0.416	kg / kg cassava chips
Water content	20.0%	%
CO2	0.22	kg
Chemicals		
Sulphuric acid (H2SO4)	0.0031	kg / kg ethanol
Alpha-amylase	0.0019	kg / kg ethanol

Ammonia (NH_3)	0.0057	kg / kg ethanol
Urea	0.0047	kg / kg ethanol
Sodium hydroxide (NaOH)	0.0025	kg / kg ethanol
Sodium hypochlorite (NaOCl)	0.0000	kg / kg ethanol
Diammonphosphate (DAP)	0.0034	kg / kg ethanol
Electricity consumption	0.274	kWh / kg ethanol
Electricity mix	Electricity mix Viet Nam	
heat consumption	12.72	MJ / kg ethanol
covered by biogas CHP	7.9%	%
covered by hard coal CHP	64.2%	
covered by wood chips CHP	27.9%	
Energy from biogas CHP		
efficiency of electricity production	0.0%	%
efficiency of heat production	90%	%
Biogas from waste water	1.12	MJ / kg ethanol
Energy from coal-CHP		
efficiency of electricity production	0.0%	%
efficiency of heat production	90%	%
hard coal	9.07	MJ / kg ethanol
Energy from wood-CHP		
efficiency of electricity production	0.0%	%
efficiency of heat production	90%	%
wood chips	3.94	MJ / kg ethanol
Allocation over main- and co-product		
Ethanol	1.0	MJ
Stillage cake	0.577	MJ/MJ Ethanol
Heating value products sum	1.577	MJ
Emissions allocated to ethanol	63.4%	%
Transport ethanol via blending station to filling station		
Transport		
Distance	522	km
Transport vehicle	Truck (40 t) for liquids	
Fuel	Diesel	
Filling station		
Electricity consumption	0.0050	kWh / kg ethanol
Electricity mix	Electricity mix Viet Nam	

7.1.3 Results

Total GHG emissions for ethanol produced from cassava cultivated at the Nui Phao pilot site in Dai Tu are 47.69 g CO2eq/MJ ethanol, of which 64% of the contribution come from ethanol processing and 28% from cassava cultivation. Table 3 and Figure 8 give an overview over all GHG emissions and savings for every step of the LCA for scenario 1.

Table 3: GHG emissions from cassava-based ethanol scenario

	Greenhouse gases					
	g CO_2 fossil	g CO2 biogenic	g CH_4 fossil	g CH4 biogenic	g N_2O	g CO_{2eq}
Land use change *(sum per ha)*		-16				**-16**
Land use change (aLUC)		-16				**-16**
Cultivation *(sum per ha)*	575436	0	1425	287.377	2455	**1349842**
Fertiliser & pesticides						
Urea	127696	0	697	0	0	**145109**
P2O5-Fertiliser	253914	0	471	0	7.60	**267954**
K2O-Fertiliser	28972	0	54.9	0	0.661	**30542**
CaO-Fertiliser (kg CaCO3)	25205	0	54.5	0	0.915	**26841**
N2O field emissions - mineral fertiliser					1562	**465359**
N2O field emissions - organic fertiliser					878	**261584**
Emissions from field burning of residues				287	2.8	**8027**
Seeds						
Cassava cuttings	47929	0	0.000	0	0.000	**47929**
Energy						
Diesel	68715	0	107	0	0.42	**71509**
Emissions from diesel usage (agriculture)					2.5	**784**
Electricity consumption (for irrigation)	23004	0	40.338	0	0.638	**24203**
Transport of cassava roots *(sum per kg cassava)*	0.69	0	0.00111	0	0.000019	**0.72**
Diesel	0.69	0	0.00111	0	0.000019	**0.72**
Chipping *(pieces by hand)*						
Diesel	0	0	0.00000	0	0.000000	**0.00**
Transport of cassava chips *(sum per kg chips)*	19.96	0	0.03198	0	0.000556	**20.93**
Diesel	19.96	0	0.03198	0	0.000556	**20.93**
Processing - ethanol plant *(sum per kg ethanol)*	1121	0	6.37	0	0.0203	**1297**
Chemicals						
Sulphuric acid (H2SO4)	0.8	0	0.0016	0	0.000	**0.8**
Alpha-amylase	1.9	0	0.0035	0	0.000	**2.0**
Ammonia (NH3)	13.9	0	0.0258	0	0.000	**14.5**
Urea	8.0	0	0.0436	0	0.000	**9.1**
Hydrochloric acid (HCl)	0.0	0	0.0000	0	0.000	**0.0**
Sodium hydroxide (NaOH)	1.9	0	0.0042	0	0.000	**2.1**
Sodium hypochlorite (NaOCl)	0.0	0	0.0000	0	0.000	**0.0**
Diammonphosphate (DAP)	5.2	0	0.0000	0	0.000	**5.2**
Emissions from energy consumption						
Electricity mix	140	0	0.246	0	0.004	**147**

Emissions from biogas-CHP	0	0	0	0.2	0.002	**5.7**
Biogas from waste water	5.1	0	0.01	0	0.001	**11**
Coal-CHP	0	0	0	0.0	0.003	**1.0**
Hard coal	929	0	6.04	0	0.006	**1081**
Emissions from chips-boiler	0	0	0	0.019	0.004	**1.6**
wood chips	16	0	0	0	0.000	**15.8**
Allocated emissions *(sum per kg ethanol)*	898	0	4.47	0.3452	0.64	**1210**
Cumulated emissions (per kg ethanol)	1415	0	7.05	0.5443	1.01	**1907**
Cumulated allocated emissions per kg ethanol	898	0	4.47	0.3452	0.64	**1210**
Transport ethanol via blending to filling station	41.4	0	0.0667	0	0.00115	**43.4**
Transport Diesel	38.8	0	0.0622	0	0.001083	**40.7**
Filling station Electricity consumption	2.6	0	0.0045	0	0.000071	**2.7**
Fuel use *(sum per kg ethanol)*	0	0	0.0008	0	0.00320	**1.0**
Emissions from Ethanol usage	0	0	0.0008	0	0.00320	**1.0**

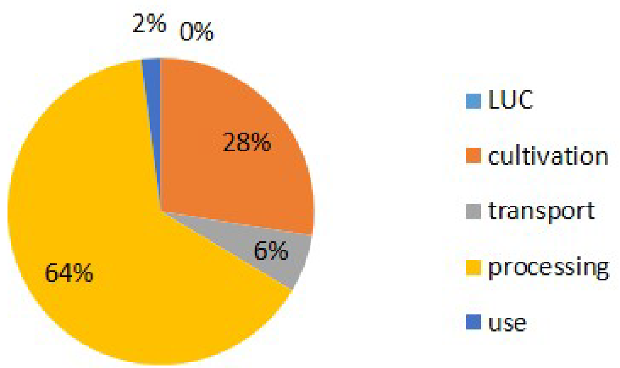

Figure 8: Share of GHG emissions from every step of the utilisation chain

The total GHG emissions from the production and use of bioethanol for transport are about 50.7% of total GHG emissions from those from gasoline (RON92) (see Table 4) or, vice versa, bioethanol production from cassava cultivated on former mining sites and its use can achieve 49% of GHG emission savings in comparison to the use of RON92 gasoline. This means that the use of E5 and E10 produced from cassava cultivated on former mining sites as a substitute for gasoline would achieve a significant GHG emissions reduction.

Table 4: GHG emissions balance: comparison between biofuel and gasoline

	Cassava-based ethanol (1)	RON92 Gasoline (2)	Saving (=[(2)-(1)]/(2))
	g CO_2eq/MJ EtOH	g CO_{2eq}/MJ gasoline	
LUC	-0.000149		
cultivation	13.115040		
transport	2.905808		
processing	30.695734		
use	0.973295		
total	**47.69**	**94.00**	**46.31** g CO_{2eq}/MJ **49.3 %**

Even though the cassava yields on marginal land such as mining sites are lower in comparison to those of conventionally produced cassava on normal agricultural land, the bioethanol produced from it has even a better emission reduction performance than conventionally produced bioethanol. According to Pirelli et al. (2018), conventional cassava-based ethanol produced in Vietnam shows avoided GHG emissions of only 37 - 39 %.[103] This is mainly due to the significant higher LUC effects of conventional cassava cultivation, as can be seen in Figure 9.

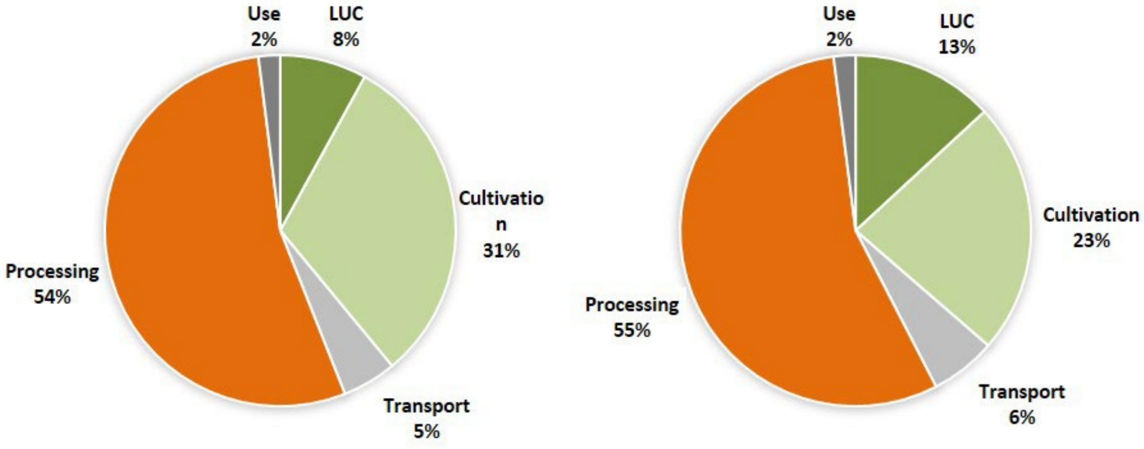

Figure 9: Total GHG emissions from conventionally produced cassava-based ethanol production on plain sites (left) and slope sites (right) in percentage

Source: Pirelli et al. 2018)

[103] Pirelli, et al. (2018)

8. Conclusion

This Paper evaluated the utilisation scenarios of cassava, VA06 grass and acacia wood as they have been developed within the CPEP project, which promotes and investigates the cultivation of energy crops on post-mining sites in Vietnam. Being marginal areas, post-mining sites are not suitable for conventional agriculture due to heavy metal contamination. Thus, the cultivation of energy crops on these sites does not compete with food production. Within the CPEP project, cassava and VA06 grass were cultivated on a test site in the Thai Nguyen Province while acacia hybrid was planted in Thai Nguyen and Quang Ninh Province. The CPEP project focuses on these crops and trees, because they resulted in being more suitable for cultivation than sweet sorghum, jatropha curcas, sunflower and Chinese wood-oil tree.

In the last few years, the Vietnamese government has implemented several policies obliging bioethanol blending and obligating mining companies to re-cultivate post-mining sites. The CPEP project thus benefits from the current political framework in Vietnam, because mining companies might use energy crops for re-cultivation to both comply with national law and to sell their products to biofuel companies. However, the implementation of environmental policies still lacks behind and diminishes the government's conservation efforts. Moreover, Vietnam's ethanol facilities face an unstable supply of feedstock due to high export prices and a high demand from starch and animal feed producers. Therefore, only 2 of 7 ethanol facilities are currently operating in Vietnam. The negotiation of cassava offtake contracts between farmers and ethanol manufacturers might be an opportunity to ensure a stable supply of feedstock to the ethanol facilities in Vietnam.

Vietnam's energy demand still increases due to economic growth, industrialisation and urbanisation. Even though renewable energy excluding hydro power just accounted for 3.7% of Vietnam's electricity generation in 2020, the country's full potential has not yet been tapped. Therefore, the Vietnamese government aims to increase the share of renewable energy on Vietnam's total power generation to 10% in 2030. Moreover, Vietnam's gasoline demand is expected to rise, while the domestic production decreases. Thus, the bioethanol production through cassava cultivated on post-mining sites both fits the current political agenda and reduces Vietnam's dependency on gasoline imports. However, decision-makers and consumers still doubt the reliability of bioenergy sources and the domestic technology still lacks behind international standards. Awareness and technology transfer campaigns might improve the reputation and efficiency of the domestic bioenergy production, respectively. Furthermore, the current price difference between E5 and RON95 gasoline seems to be insufficient for consumers to prefer the first over the latter. Therefore, the Vietnamese government needs to increase the price differences for example through import tariffs and CO2 taxes on fossil fuels.

The domestic bioethanol industry in Vietnam is specified in using cassava as the only feedstock. In the CPEP project on the test site in Thai Nguyen Province, the cassava yield was 24.92 tonnes per hectare. The average yield stated in the literature varies between 12.73 and 35 tonnes per hectare. Accordingly, the cultivation of cassava on the test site was rather successful. However, the yield of fresh cassava only resulted in 1.9 tonnes of ethanol, which is 1.5 tonnes less than on average and might indicate a low sugar content of the cassava tubes probably caused by low soil fertility. The follow-up project will more precisely analyse the cassava harvest making it possible to detect such pitfalls. It will also optimise cultivation techniques to further increase yields.

In Vietnam, the average dry matter yield of VA06 grass in the south central coastal provinces varies between 26.4 and 39 tonnes per hectare and year while it is 66.65 tonnes in mountainous regions in the northwest.

Within the CPEP project, the dry matter yield varied between 25.5 and 33 tonnes per hectare and year, making it comparable with the yields of the south central coastal provinces. VA06 grass serves as forage for livestock while the resulting manure can be processed into biogas by small-scale biogas digesters. However, many farmers lack financial resources and tend to discharge the manure to the environment thereby causing additional greenhouse gas emissions and environmental pollution. Therefore, they need further technical support and advice about biogas technology. On the farm, the biogas can be directly used for cooking while the digestate serves as fertiliser on the fields. Consequently, farmers in remote areas become less dependent on electricity, fossil fuels, firewood and chemical fertilisers and get the opportunity to add value to their waste. Even though there are around 500,000 small-scale biogas digesters in Vietnam, farmers lack economics on scale and large-scale biogas facilities are still missing. Therefore, the production of biogas from VA06 grass cultivated on post-miming sites is currently less promising than the production of bioethanol from cassava.

Acacia hybrid can be co-fired in coal thermal power plants to generate electricity. However, as long as the CIF price of imported coal does not increase, the combustion of acacia wood is less efficient and competitive than the combustion of coal. Therefore, owners of coal power facilities probably prefer coal to acacia wood for electricity generation if there will be no further financial incentives through political measures. Therefore, the combustion of co-firing acacia wood in coal thermal power facilities has not been further considered in the CPEP project.

In summary, cassava, VA06 grass and acacia hybrid were all successfully cultivated on the test sites of the CPEP project. Nevertheless, the current bioenergy infrastructure and bioethanol blending obligations favours the production of bioethanol from cassava. Therefore, the follow-up project is focusing on the cultivation of cassava on post-mining sites. Additionally, the cassava-bioethanol utilisation chain resulted in having remarkable positive effects regarding climate change mitigation. It could be modelled that, compared to the use of conventional RON92 gasoline, fuel produced with bioethanol from cassava cultivated on former mining sites can save up to 49.3 % in CO_2 emissions. Moreover, the potential CO_2 savings of bioethanol from cassava from the examined mining sites are even higher than those that occur through the use of conventionally produced cassava-based bioethanol in Vietnam, since the negative climatic effects of land use changes are much lower. In addition, the cultivation of cassava on former mining sites avoids competition for land with food production and therefore seems to be a more sustainable way for Vietnam for meeting its increasing national bioenergy demand in the future.

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