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UNIVERSITY OF SCIENCE AND TECHNOLOGY OF HANOI
Department of Renewable Energy

Feasibility and Sustainability of Co-firing biomass in coal power plants in Vietnam

Master thesis

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9/9/2015

FEASIBILITY AND SUSTAINABILITY OF CO-FIRING BIOMASS IN
COAL POWER PLANTS IN VIETNAM

by

Truong An Ha

A thesis submitted in the partial fulfillment
of the requirements for the degree

of

MASTER OF SCIENCE

in

Renewable Energy

Approved:

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Truong An Ha

and

University of Science and Technology of Hanoi (USTH)

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2015

ABSTRACT

Feasibility and sustainability of co-firing biomass in coal power plants in Vietnam

English

The technology of co-firing biomass with coal is well-matured as demonstrated in many power plants in Europe and the US. It is considered a low-cost technology to utilize biomass in power generation as well as to reduce the greenhouse gases emissions and coal consumption in coal power plants. In Vietnam, the factors that draw attention to biomass co-firing include national energy security, climate change and environmental issues. To ensure national electricity security, the capacity of coal power plants in Vietnam will be expanded to 75 GW by 2030, which accounts for 57% of total power generation. This will increase the greenhouse gases emissions and pose a great challenge on coal supply for Vietnam. This research aims to evaluate the feasibility and sustainability of co-firing biomass in coal power plants in Vietnam through a set of indicators, which covers technical, economical, environmental and social aspects. These indicators are calculated for two cases, a newly constructed 1080 MW fluidized bed coal power plant and a 100 MW pulverized coal power plant. In the case study, direct co-firing technology with 5% of biomass is selected for the evaluation of the indicators. Results indicate that co-firing is technically feasible but not yet economically profitable for the plants to employ this technology without supporting mechanisms. However, from the environmental and social aspects, co-firing can offer various benefits including greenhouse gases emission reduction of about 10-11%, extra income for farmers and coal export company and jobs creation. Thus, it is recommended that co-firing is still an option to be considered as a way to reduce emission and to utilize biomass resource for electricity generation in Vietnam.

Keywords: biomass co-firing, feasibility, sustainability, indicators, coal, Vietnam

French

La technologie de la co-combustion de biomasse avec le charbon est prête à l'utilisation comme il est démontré dans beaucoup de centrales électriques en Europe et aux États-Unis. On considère que c'est une technologie relativement bon marché que d'utiliser la biomasse pour produire de l'électricité et pour réduire les émissions de gaz à effet de serre ainsi que la consommation de charbon dans les centrales électriques à charbon. Au Vietnam, les facteurs qui attirent l'attention vers la co-combustion de biomasse incluent l'indépendance énergétique et la souveraineté nationale, les questions de changement climatique et d'environnement. Pour assurer la capacité des centrales électriques au charbon, le Plan prévoit de la développer jusqu'à 75 GW en 2030, ce qui implique 57% de la production électrique totale. Cela augmentera les émissions de gaz à effet de serre et posera la question de ressources en charbon pour le Vietnam. Notre recherche veut évaluer la possibilité et la durabilité de la co-combustion de biomasse dans les centrales électriques au charbon au Vietnam. Pour cela, on envisage une série d'indicateurs qui couvre les aspects technique, économique, environnemental et social. Ces indicateurs sont calculés pour deux cas, une centrale récemment construite, à charbon fluidisé de 1080 MW, et une centrale à charbon pulvérisé de 100 MW. Dans ces études de cas, la technologie de co-combustion directe avec 5% de biomasse est sélectionnée pour l'évaluation des indicateurs. Les résultats montrent que la co-combustion est techniquement réalisable mais pas encore profitable économiquement pour les deux centrales si on emploie cette technologie sans mécanismes pour la soutenir. Cependant, du point de vue

environnemental et social, la co-combustion peut offrir des bienfaits comme la réduction de gaz à effet de serre d'environ 10-11%, un revenu supplémentaire pour les fermiers et la compagnie d'exportation du charbon ainsi que des créations d'emplois. Ainsi, on recommande que la co-combustion soit une option à considérer, comme un moyen de réduire l'émission de gaz à effet de serre et un moyen d'utiliser les ressources de biomasse pour produire de l'électricité au Vietnam. On peut ainsi également réduire la pollution de l'air causée par l'incinération des déchets agricoles en plein champ. C'est une option qui mérite d'être étudiée davantage.

Mots-clés: biomasse co-combustion, faisabilité, durabilité, indicateurs, charbon, Vietnam

Vietnamese

Công nghệ đồng đốt sinh khối với than đã được ứng dụng tại nhiều nhà máy nhiệt điện than ở Châu Âu và Hoa Kỳ. Đây là công nghệ tận dụng sinh khối để phát điện có chi phí đầu tư tương đối thấp cũng như có tiềm năng giảm phát thải khí nhà kính tại các nhà máy nhiệt điện than. Tại Việt Nam, các yếu tố thu hút sự quan tâm đến đồng đốt sinh khối với than bao gồm an ninh năng lượng quốc gia, biến đổi khí hậu và các vấn đề môi trường. Để đảm bảo an ninh năng lượng, Việt Nam sẽ tăng tổng công suất lắp máy của các nhà máy nhiệt điện than lên 75 GW vào năm 2030, khi đó sản lượng điện từ nhiệt điện than sẽ chiếm 57% tổng sản lượng điện. Việc này sẽ dẫn đến sự gia tăng phát thải khí nhà kính và đặt ra thách thức trong việc cung ứng than cho các nhà máy nhiệt điện than ở Việt Nam. Mục đích của báo cáo này là nhằm đánh giá tính khả thi và tính bền vững của đồng đốt sinh khối với than tại các nhà máy nhiệt điện than ở Việt Nam thông qua một bộ các chỉ số bao gồm các khía cạnh về kỹ thuật, kinh tế, môi trường và xã hội. Những chỉ số này sau đó được tính toán cho hai trường hợp: một nhà máy nhiệt điện mới đi vào vận hành, công suất 1080 MW sử dụng công nghệ tầng sôi và một nhà máy điện điện đã vận hành nhiều năm, công suất 100 MW sử dụng công nghệ than phun. Trong tính toán này, công nghệ đồng đốt trực tiếp sinh khối với than ở tỉ lệ 5% được giả thiết áp dụng đối với cả hai trường hợp để đánh giá các chỉ số. Kết quả cho thấy công nghệ đồng đốt có khả năng áp dụng được về mặt kỹ thuật, tuy nhiên lại chưa cho thấy tính khả thi về mặt kinh tế nếu như không có các cơ chế hỗ trợ. Mặt khác, về môi trường và xã hội, công nghệ đồng đốt cho thấy lợi ích trên nhiều khía cạnh, bao gồm giảm phát thải khí nhà kính từ 10-11%, tăng thêm thu nhập cho nông dân cũng như tạo công ăn việc làm. Do đó, đồng đốt sinh khối với than vẫn nên được xem xét như một cách tiếp cận trong việc giảm phát thải khí nhà kính cũng như tận dụng nguồn năng lượng sinh khối để sản xuất điện tại Việt Nam.

Từ khóa: sinh khối, đồng đốt, tính khả thi, tính bền vững, chỉ số, than, Việt Nam

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Truong An Ha

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Acronyms

ACT	Avoided Cost Tariff
BAU	Business As Usual
CHP	Combined Heat and Power
CRF	Capacity Recovery Factor
EVN	Electricity of Vietnam
IPCC	International Panel of Climate Change
IRENA	International Renewable Energy Agency
FTE	Fulltime Equivalence
GBEP	Green Bioenergy Partnership
GENCO	Power Generation Corporation
GHG	Greenhouse Gas
LCOE	Levelized Cost of Electricity
LHV	Lower Heating Value
MOC	Ministry of Construction
MOIT	Ministry of Industry and Trade
MONRE	Ministry of Natural Resource and Environment
NPDP	National Power Development Plan
NREL	National Renewable Energy Laboratory
NPV	Net Present Value
O&M	Operation and Maintenance
PECC	Power Engineering Consultation Company
UNDP	United Nation Development Program
UNEP	United Nation Environmental Program
USAid	United States Agency for International Development
VINACOMIN	Vietnam National Coal and Mineral Industry Holdings Limited
WACC	Weighted Average Cost of Capital
UScent	United State cent
USD	United State Dollar
VND	Vietnam Dong

Units

GW	Giga Watt	= 10^9 Watt
ha	Hectare	= 10^4 square meter
kWh	Kilo Watt hour	= 3.6×10^6 joule
MJ	Mega Joule	= 10^6 joule
TJ	Tetra Joule	= 10^9 joule
Mtoe	Million ton oil equivalence	= 41.686×10^9 joule
Mton	Million ton	= 10^9 kilogram
MW	Mega Watt	= 10^6 Watt
MW _e	Mega Watt electricity	
PJ	Peta joule	= 10^{15} joule
TWh	Tetra Watt hour	= 3.6×10^{12} Joule

1. Introduction

In 2013, total installed capacity for electricity production in Vietnam was 30,500 MW (Institute of Energy-MOIT 2014), of which, the capacity of coal thermal power plants was 6,863 MW, account for 22.5% total installed capacity of the country. The sharing of coal power plants in electricity generation in 2013 was 20.5% of total 131.1 billion kWh. According to the National Power Development Plan (NPDP) VII for electricity development, the installed capacity of coal power shall increase by 30,000 MW, equivalence to 50.1% total capacity by 2020. In 2030, the share of electricity production from coal power plant will grow up to 57.8% total power production of the nation. By August 2014, 14 coal power plants are operating, and the technologies applied include pulverized coal (PC) and circulating fluidized bed (CFB) technology. In which, 9 plants are using PC technology and the others are CFB power plants (Institute of Energy-MOIT 2014). The electricity demand of Vietnam will increase dramatically in the following decades as demonstrated in the NPDP VII. Therefore, the expansion of coal-fired power plant in Vietnam is critical to ensure the national electricity security for socioeconomic development in the country.

With the dominance of coal power plant as predicted, the greenhouse gases (GHG) emission from coal firing will increase and account for large portion in total GHG emission of Vietnam. Burning coal to generate electricity will release the huge amount of carbon dioxide, which once captured by pre-historic plants millions of year ago, as well as other greenhouse gases such as NO_x into the atmosphere. It is also need to be noted that the coal mining process emits methane, which is 21 times more powerful than carbon dioxide in term of causing greenhouse effect. Other environmental problem associated with coal-fired coal power plants is SO_x emission that causes acid rain. Vietnam is listed in the top countries that most vulnerable to climate change, therefore the urge for finding solution to cut down GHG emission is now more visible than ever (MONRE 2014).

Another issue that coal-fired power plants will face is coal shortage as the domestic coal reserves are depleting. With the share of electricity from coal power plants expected to reach 52% in 2030, the demand for coal will increase in great quantity. By 2030, about 43 GW out of 77 GW total installed capacity of coal power plants will have to rely on imported coal. The amount of coal to be imported by then is estimated at 80 million tons per year (M. H. Nguyen et al. 2011). As a consequence of coal scarcity, the price of coal should increase over time. Currently, the cost for coal already accounts for 32-40% of the electricity production cost, and this will also increase in line with coal price (Institute of Energy-MOIT 2014). With the coal price at present, a new coal power plant project in Vietnam with the investment rate of 1,400-1,600 USD/kW should sell electricity at 7.5 – 7.9 UScent/kWh to ensure the investors' benefit. This electricity tariff is much higher than the current tariff in Vietnam, which is about 5.5 - 6 UScent/kWh (Institute of Energy-MOIT 2014). Therefore, to ensure the economical benefit while the coal price increase, the coal power plants should seek for a way to reduce the fuel cost.

Of all the available technologies, co-firing biomass with coal could be considered as a promising solution to these issues related to coal power sector and a better way to utilize biomass resources in Vietnam for following reasons.

- Vietnam has a great potential of biomass, especially from agriculture residue.
- Biomass can partly substitute coal, thus reduce the amount of coal used and provide the possibility to reduce the fuel cost while coal price increase.
- Through biomass co-firing, the demand for coal in electricity sector will be lower, thus the domestic coal reserves could last longer.
- Co-firing has potential to reduce GHG emission.
- Significantly lower investment cost than biomass-based power technologies.
- With co-firing, the plant can use biomass whenever it is available. Power plants could still be operated with coal even when biomass is unavailable due to unexpected reasons.
- Experiences in biomass co-firing already exist world-wide.

1.1. Objectives of the research

Although biomass co-firing has been widely studied and demonstrated in many countries, this is still a new concept in Vietnam. At present, there is still a big gap in study/research on biomass co-firing in general or biomass co-firing in coal power plants in particular in Vietnam. This research is conducted in order to provide a general view on the feasibility and sustainability of biomass co-firing in coal power plants in Vietnam. Presently, the set of indicators for sustainable evaluation of bioenergy system is well-developed (GBEP 2011)(Dale et al. 2013)(McBride et al. 2011)(Evans, Strezov, and Evans 2010), however, these indicators are quite broad and not all indicators can be applied or necessary for the assessment of biomass co-firing. Therefore, the aim of this study is to construct the indicators that are more specific for biomass co-firing and for the context of Vietnam.

The aims of this research include (1) reviewing biomass potential in Vietnam for power generation and biomass conversion and co-firing technologies, (2) building a set of indicators to evaluate the feasibility and sustainability of co-firing in coal power plants in Vietnam, which can be served as a general method to quantify the costs and benefits of co-firing technical assessment and technical choice, and (3) applying these indicators in case studies to assess technical and economical feasibility as well as social, economic and environmental sustainability for two real coal power plants that are operating in Vietnam.

1.2. Organization of the report

This report consists of six chapters. The introduction provides brief information about the study, the approach to research questions and objectives of the research. Chapter 2 and 3 give the review on Vietnam energy sector, biomass potential, biomass conversion technology and biomass co-firing. Chapter 4 describes the method used as well as the determination of indicators for feasibility and sustainability assessment. In this chapter, a set of indicators is built which covers technical, economical, environmental and social dimensions.

In Chapter 5, two coal power plants are selected to be case studies. The indicators are calculated for both cases to evaluate the feasibility and sustainability of biomass co-firing at these plants. Discussion on the result is also provided in this chapter. Based on the results and discussion, conclusion can be found in the last chapter.

2. Biomass to electricity in Vietnam

2.1. Electricity demand and supply in Vietnam

The electricity consumption in Vietnam is growing rapidly as a consequence of the fast growth of economy and industrialization over the last two decades. During 20 years from 1992 to 2012, the electricity consumption of Vietnam has increased from 7 TWh to 108 TWh (“International Energy Statistics” 2015), which correspond to the average annual growth rate of 13.7% (see Figure 1).

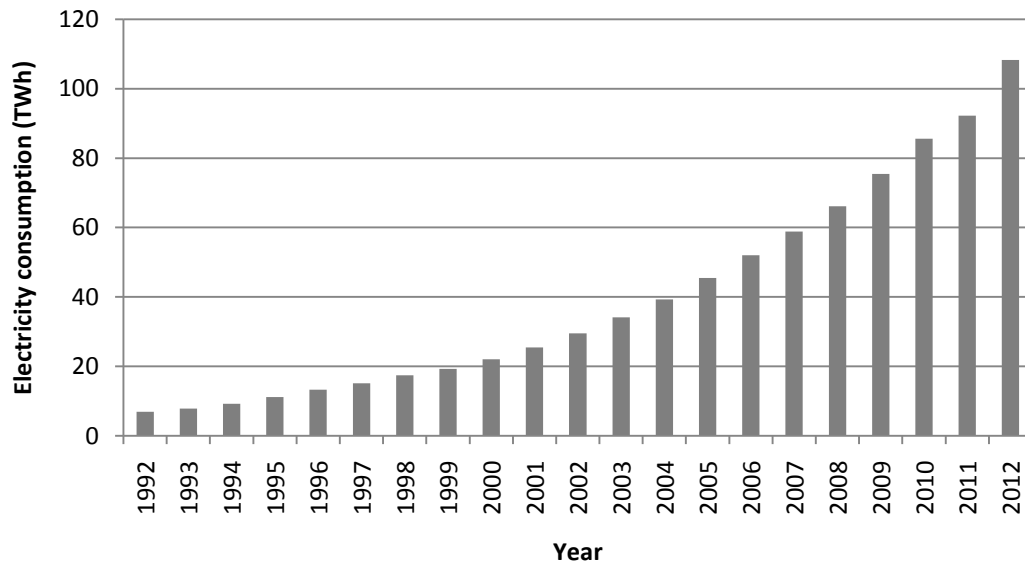


Figure 1. Electricity consumption in Vietnam (“International Energy Statistics” 2015)

The electricity demand of Vietnam is also expected to increase in the next decades as stated in the latest Power Development Plan: the average annual growth rate of electricity demand was set at 12.7% during 2011 – 2020 and 7.8% during 2021 – 2030. To meet this increasing need of electricity, the power supply will reach 330 - 362 TWh in 2020 and 695 – 834 TWh in 2030, which corresponds to a 14% average annual growth rate between 2015 and 2020 and 10% between 2020 and 2030 (“National Power Development Plan 7” 2011). By the end of 2014, the total installed capacity of Vietnamese power plants was 34 GW. To ensure the electricity supply, the total installed capacity shall be extended to 75 GW by 2020 and to 146.8 GW by 2030 and Vietnam will continue to import electricity from other countries. Currently, Vietnam is a net importer of electricity with the total import in 2012 is 3850 GWh while the total export is only 535 GWh (IndexMundi 2015). The country will still need to acquire 3% to 5% of total electricity supply from importing to ensure the national electricity security during 2015 – 2030 (“National Power Development Plan 7” 2011).

To supply electricity for socioeconomic development, the power production sector in Vietnam is utilizing different primary sources of energy including fossil fuel, hydropower, biomass and renewable energy. However, the majority proportion of power generation is derived from fossil fuels (coal, natural gas and oil) and hydropower. The proportion of electricity supplied by type of sources in year 2012 and forecast for 2020 and 2030 is demonstrated in Figure 2. By 2012, the biggest share in electricity generation was fossil fuel with 49% (of which, gas and oil accounted for 31% and 17%

for coal), followed by hydropower with 47.5% of total electricity supply (To 2013). These sources added up to 96.1% total electricity supply of Vietnam and electricity imported constituted of 3.5%, which left an insignificant share of 0.2% for biomass and other renewable energy (wind and solar). In the National Power Development Plan VII, a roadmap for electricity development has been approved by the Prime Minister, in which the share of coal in electricity production will expand to 48% in 2020 and 52% in 2030 and this will make coal-fired power plants to be the biggest electricity producers in Vietnam. On the other hand, electricity generated from gas and oil will be reduced from 31% in 2012 to 16.5% in 2020 and to 11.8% in 2030. Similar to oil, the share of hydropower will also shrink significantly from 47.5% to 25.5% in 2020 and to 15.7% in 2030. The Plan also set target for renewable sources development which will cover 5.6% of total electricity supply in 2020 and 9.4% in 2030.

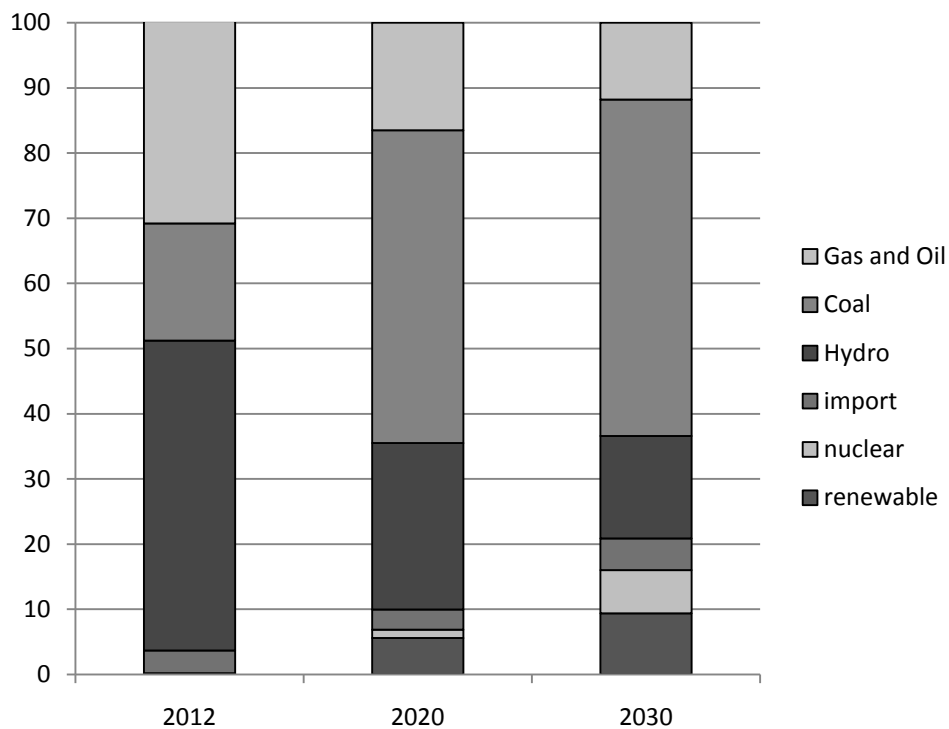


Figure 2. Electricity supply by type of sources (To 2013) (“National Power Development Plan 7” 2011)

Figure 2 shows that in 2012 about 50% of generated electricity come from the combustion of coal, gas and oil. In the next decades, the use of fossil fuel in electricity generation in Vietnam will increase to reach approximately 65% of total electricity generation as the installed capacity of fossil fuel based power plants will expand to 48,400 MW in 2020 and to 92,300 MW in 2030 (“National Power Development Plan 7” 2011). The domination of fossil fuels in power generation led to the high intensity of greenhouse gas (GHG) emission from Vietnamese energy sector (see Figure 3). The greenhouse gas inventory of Vietnam in 2010 estimated that the GHG emission from energy sector is 141 Mton CO₂ equivalent (CO₂e), which accounts for 53% of total emissions (exclude land use, land-use change and forestry) of 266 Mton CO₂e. Of which, the share of emission from burning fuels is 88.03%, equivalent to 124 Mton CO₂e (MONRE 2014) .

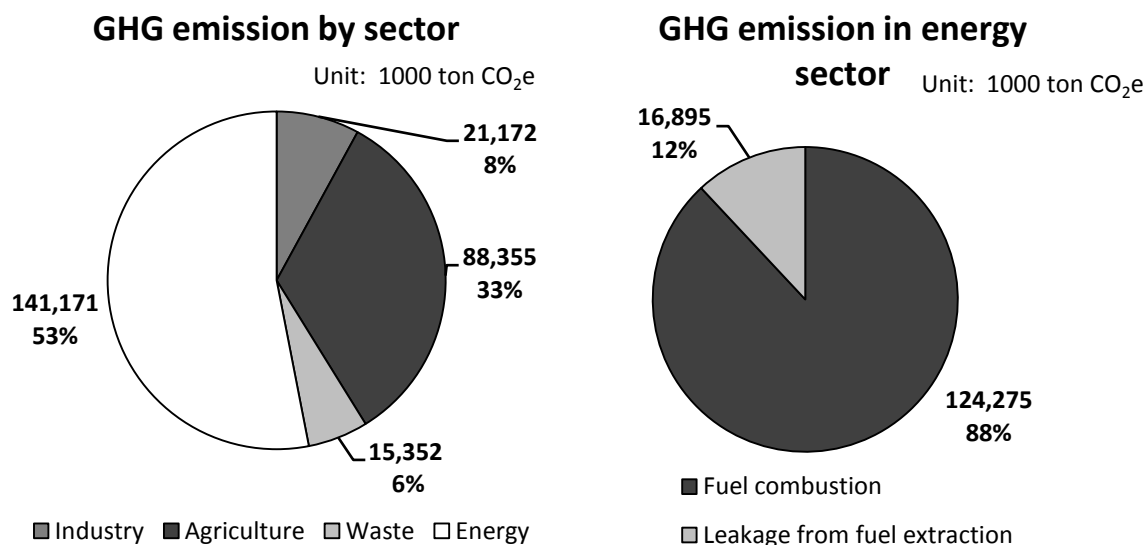


Figure 3. GHG emission by sector (left) and in energy sector (right) (MONRE 2014)

As can be seen from the statistical data above, Vietnamese electricity sector is now facing with several constraints (i) rapid growth of energy demand, (ii) shortage in energy supply, (iii) high dependence in fossil fuels and (iv) GHG emission from electricity generation. Moreover, the Government has set up target for GHG emission reduction in power sector in 2011 - 2020 period at the rate of 10 - 20% compare to the the Business As Usual (BAU) scenario (Prime Minister 2012). By 2030, the rate of emission reduction in energy sector will reach 20 - 30% compared to BAU scenario. This will be a great challenge for the energy sector of Vietnam based on present circumstances. Due to the current and projected situation of electricity demand and supply in Vietnam, it is necessary to find alternatives to ensure national energy security as well as to control and reduce greenhouse gas emission in the power production sector of Vietnam.

2.2. Biomass for energy in Vietnam

2.2.1. Biomass availability in Vietnam

Being an agricultural country, Vietnam has a great potential on biomass sources in large quantity that can be utilized for producing energy. Biomass has also been used as energy source in daily life for long time. It is estimated that about 90% of domestic energy consumption in rural area and a significant portion of energy for small industry come from biomass such as fuel wood, agricultural residue and charcoal.

Biomass that can be used in energy production can be categorized in several types such as agriculture residue, dedicated energy crops, forestry and waste (wood waste, municipal solid waste and manure). Within the scale of this research, only the biomass sources relevant to co-firing will be discussed. Table 1 and 2 provide a summary of fuel characteristics of some biomass types and the potential of biomass in term of energy.

Residue of agricultural crops

This is the most abundant and the easiest to access source of biomass. There are many varieties of agricultural residues which include post harvest residues such as rice straw, corn stove and post processing residue such as rice husk, bagasse, coffee husk and coconut shell.

Rice residues. Vietnam is the second rice exporter in the world and with the large scale rice cultivation, there is a huge amount of rice residue produced each year. Nguyen (2011) estimated that the annual production of rice husk and rice straw in 2010 is about 8 million tons and 40 million tons, respectively. The calculation is based on the residue to product ratio (RPR) rice husk and rice straw. Moisture content of rice straw ranges from 12-22 % on wet basis, while that of rice husk is 8-12% (see Table 1). The Lower Heating Value (LHV) of rice residues varies from 10.9 to 12.6 MJ/kg for rice straw and from 10.8 – 12.1 MJ/kg for rice husk (D. C. Nguyen 2011). The total energy contain in rice husk is calculated at 89.3 PJ, given the LHV of rice husk is 11.9 MJ/kg. Theoretically, this amount of rice husk can generate approximately 8.2 TWh of electricity (given the standard efficiency of energy conversion to electricity is 33%). Similarly, the energy content and theoretical potential electricity produced from rice straw is estimated at 432.8 PJ and 39.7 TWh (see Table 2), with the LHV of rice straw at 11.5 MJ/kg. The rice husk and rice straw energy potential could account for more than 55% of the total electricity consumption in 2010 which is 85.6 TWh (see Figure 1). Rice production is concentrated in Mekong River Delta in the South and Red River Delta in the North, which respectively account for 50% and 20% of rice production in Vietnam.

Previously, rice straw was utilized as a fuel for cooking and heating in the rural area as well as fertilizer for the field (while left in the paddy field after harvesting). However, at present most of the rice straw is burned and cause serious air pollution. Rice straw is produced during the rice cultivation seasons. There are three rice cultivation seasons in Mekong Delta and only two in Red River Delta. The drawback of rice straw is that it will cost to collect in large quantity for usage. In some provinces in Mekong River Delta such as An Giang Province, farmers begin to use straw winders to collect straw for commercialization. One roll of straw weights about 12 – 15 kg and can be sold at 30,000VND/roll for the dealers (Hoang Thai and Giao Linh 2015). These straw rolls are mostly used for growing mushroom and feeding animals.

Rice husk is produced in the rice mills; therefore it is more concentrated than rice straw. This makes rice husk collecting easier. The production of rice husk, not like that of rice straw, depends on the supply chain of the rice market. Traditionally, rice husk is used as fuel for domestic cooking, ceramic/brick kilns. In recent years, more and more energy investors pay attention to the development of rice husk power plants and rice husk briquette production for commercialization.

Corn residue. Vietnam corn production has increased steadily as the result of demand for animal feed. The corn production in 2010 reached 6 million tons. The main production seasons are winter-spring (from December to April) and summer-autumn (from April to August). Corn is cultivated mainly in the Central Highlands, North East, South East and North Central Coast regions. The average waste to maize weight ratio is 2.5. In 2010, the production of corn residue was about 15 million tons (Leinonen and Nguyen 2013). With the Lower Heating Value (LHV) of corn residue at wet matter basis of 16.6 MJ/kg (Tran 2011), the energy content and potential electricity generation from corn residue is calculated at 248.4 PJ and 22.8 TWh, respectively (see Table 2). The wastes include corn

cobs, corn stalk and corn husk. The primary usage of corn residues are animal feed and domestic fuel. However, more and more corn residues are dumped which becomes a source of environmental pollution.

Sugar cane residue. Total production of sugar cane of Vietnam in 2010 was 24 million tons and the total bagasse output was 7.2 million tons (Leinonen and Nguyen 2013). Most of the bagasse is currently used in the combined heat and power (CHP) boiler of the sugar mills to supply electricity and heat for their own process. The amount of cane trash produced in 2010 was 2.4 million tons.

Coffee residue. The residue of coffee cultivation and processing is coffee bean shell. The residue to product ratio of coffee bean is 0.13, which means for each kg of coffee bean, there will be 0.13 kg of coffee bean shell. With the total coffee bean production in 2010 was 1.1 million ton, the amount of coffee bean shell was 0.165 million tons. Coffee residue is being handled in different ways, either burned out in the open or disposed or used as fertilizer. Dry coffee bean shell is sometime used as a primary fuel source for coffee dryers at some small-scale facilities (SNV 2012).

Tea residue. Tea is an industrial perennial that grown mainly in mountainous area throughout the country. The product collected from tea plants is tea leave, thus little residues are produced during the process. Typically, at times of replanting, wood residue is generated but these are used for tea drying (SNV 2012). Therefore, in this study tea is not considered as a potential biomass source for energy production for its residue.

Biomass type	RPR	Moisture content	LHV (wet matter)
Rice straw	1:1	12-22	10.9-12.6
Rice husk	0.2:1	8-12	10.8-12.1
Corn residue	2.5:1	6-8	15.0-15.5
Bagasse	0.3:1	50	7.5
Coffee husk	0.13:1	10-12	15.4-15.8
Coconut shell	0.15:1	10-20	14.8-16.9
Fuel wood	-	20	14.8
Saw dust	-	50-55	7.2-8.4

Table 1. RPR and Fuel characteristic of some agricultural residues (Leinonen and Nguyen 2013)

Wood energy

Fuel wood, such as tree trunk, tree branch, shrubs, is collected by cutting or pruning trees. Fuel wood comes from forestry sector including natural forest (deforestation, forest fires), forest plantation, grass land and the thinning and pruning of industrial perennials (tea, coffee, rubber, cashew and so on).

Wood wastes is the by-products from wood processing at sawmills and furniture making. These wastes consist of wood chips, butt ends, bark and saw dust. The total amount of wood waste from sawmills in 2010 was 6.7 million tons, including 5.58 million tons of wood residues and 1.12 million tons of sawdust (D. C. Nguyen 2011).

Biomass type	LHV (MJ/kg) of wet matter	Total biomass potential (wet) (million ton)	Total energy content in residue (PJ)	Potential electricity generated (33% of efficiency) (TWh)
Rice straw	11.5	37.6	432.8	39.67
Rice husk	11.9	8	89.3	8.19
Corn residue	16.6	15	248.4	22.77
Bagasse	6.5	7.2	54.4	4.99
Cane trash	15.1	2.4	37.2	3.41
Cassave stem	15.1	2.28	34.5	3.16
Coffee husk	15.5	0.4	6.3	0.58
Coconut shell	15.8	0.14	2.2	0.20
Fuel wood	14.8	27.6	407.4	37.35
Wood waste	7.6	4.1	30.8	2.82
Total		104.72	1343.3	123.14

Table 2. Theoretical biomass potential in Vietnam in 2010 (Tran 2011)

Table 2 shows that Vietnam has great physical potential for heat and power generation from biomass with the total theoretical potential of electricity that can be generated from biomass of 123TWh per year. However, the practical potential is much lower than this number because the actual amount of biomass that are available for power generation is subjected to the biomass collection, biomass utilization for other purposes and biomass market. Nevertheless, the use of biomass in term of energy source is still limited in domestic cooking and heating and small rural industries. Current technologies applied for utilizing biomass in Vietnam is mostly biomass combustion for heat generation. Power and heat co-generation is only available in sugar mills using bagasse. At the moment, the development of biomass energy in Vietnam has not met the potential yet. Since biomass is considered as a renewable and carbon neutral source of energy, investment into bioenergy is a promising direction toward low-carbon-emission and low-fossil fuel-dependant power sector.

2.2.2. Current uses of biomass in electricity production and policies for bioenergy development in Vietnam

Vietnam has huge potential of converting biomass to electricity. However, the implementation of biomass power plant in Vietnam is limited to the sugar plants which utilize the in-site bagasse as fuel. Presently, there are 40 bagasse cogeneration units installed at 40 sugar mills with capacity range from 1 to 25MWe that add up to 150MWe of total capacity. Of which, only 5 plants sell their surplus electricity to the grid at very low price (4UScent/kWh) (D. C. Nguyen 2013).

By November 2011, there are about 10 proposed projects on rice husk power plant in Mekong River Delta (D. C. Nguyen 2011), but there is no such plant being implemented. For example, the investment of Lap Vo rice husk power project is approved in 2008 by Dong Thap Province but then the investment license is then revoked because the project has not been implemented by the

investor (Dong Thap People's Committee 2014). Only one combined heat and power (CHP) plant (Dinh Hai Rice husk Cogeneration Project) that burn rice husk as fuel is operating, however, at the moment only steam is generated to sell to other plants in Tra Noc Industrial Park and no electricity produced because power generation is not profitable due to low power tariff (Leinonen and Nguyen 2013). In 2013, a 20 rice husk power plants project in Mekong River Delta with total installed capacity of 200MW has been proposed by a Malaysia company. The first plant of this project will be constructed in Hau Giang Province and the Engineering, procurement and construction (EPC) contract has been signed (PECC2 2013). When completed, this will be the very first rice husk power plant in Vietnam. By August 2014, the project is still waiting for the estimated power tariff to be issued by Ministry of Industry and Trade (MOIT) because there is no regulation or guidance on power tariff for biomass power plant available yet. The project cannot be implemented until EVN receive the power tariff from MOIT (HGTV 2014). Another option for rice husk utilization for power generation is gasification technology, which is demonstrated as feasible in many small scale rice husk gasification facilities in Cambodia. However, a study of H. N. Nguyen et.al (2015) has shown that rice husk gasification as done in Cambodia is not likely to succeed when adopted in the context of Vietnam market.

The under-developed situation of biomass electricity in Vietnam might result from the lack of mechanism to support the investors in this field, low electricity tariff and high investment costs. In Decision 24/2014/QD-TTg dated 24 March 2014 of the Prime Minister on mechanisms to support biomass power project in Vietnam, the power tariff for co-generation (e.g., power production in sugar plants) is only 5.8 UScent/kWh which is lower than the tariff for coal power plant (6.6 UScent/kWh). The Decision also states that the power tariff for biomass power plant will be set in the Avoided Cost Tariff (ACT), issued annually by the Ministry of Industry and Trade. However, up until now this ACT has not been published yet.

In addition, the investment cost for biomass power plant is very high, ranges from about 2000 to 7000 USD/kW (See table 3 below). In Vietnam, for instance, the investment cost for Hau Giang Rice Husk Power Project was estimated at 31 million USD with the total capacity of 10 MW, which equivalence to the investment rate of 3100 USD/kW (Huy Phong 2013). With the very high incremental cost, compared to about 1,100 USD/kW for coal power plant (MOC 2013), the levelized cost of electricity (LCOE) of biomass power plant is about 12 UScent/kWh (D. A. T. Nguyen 2014). This LCOE is much higher than the current electricity tariff set by the government, suggested that it might not profitable to invest in producing electricity from biomass in Vietnam at the moment. Therefore, the most important barrier for developing biomass power plant in Vietnam is the economic barrier.

2.2.3. Opportunity from biomass co-firing

As the investment on 100% biomass power plants in Vietnam is still facing economic difficulty, biomass co-firing could be an interesting alternative for utilizing biomass to produce electricity. The advantages of co-firing with coal over dedicated biomass power plants include lower investment cost and not required continuous biomass supply.

Table 3 compares several technological options for power generation from biomass. Except from co-firing, all these technologies require much higher investment cost than coal power plant. This is

because co-firing can utilize the facilities of existing coal power plant. Thus, in the current situation of bioenergy in Vietnam, investing in biomass co-firing is more likely to be feasible in term of economy than in dedicated biomass power plant.

Another challenge for 100% biomass power plants is biomass supply. These plants need a continuous supply of biomass to operate. For co-firing, however, there is no need for continuous biomass supply because the plant can burn coal if biomass is not available.

Biomass power plant technology	Investment costs (USD/kW)
Stoker boiler	1880 - 4260
Bubbling and circulating fluidized boilers	2170 – 4500
Fixed and fluidized bed gasifiers	2140 – 5700
Stoker CHP	3550 – 6820
Gasifier CHP	5570 – 6545
Co-firing	<u>140 - 850</u>

Table 3. Investment costs of different technologies for biomass power plant (IRENA 2012)

3. Biomass conversion technologies

3.1. Power generation technologies from biomass

People have been using biomass to satisfy the energy needs for thousands of years. The most primitive form of biomass conversion to energy is burning wood to get heat and light. Throughout time, the technologies to extract energy from biomass have been improved greatly and diversified into many pathways. These pathways are divided into 2 main categories: Thermochemical conversion and biochemical conversion (Boyle 2004). The final products of bioconversion are heat, electricity and fuel. Figure 4 illustrates the biomass conversion routes and their products.

Biochemical conversion involves the action of microorganism to produce biogas or biofuel (bioethanol and biodiesel). The basic principle of biochemical conversion is the breakdown of sugar or other substances in biomass into ethanol, methane and other fuel, chemicals and heat. Bioconversion process can be divided into (i) *anaerobic digestion* in which the organic matters is degraded by anaerobic bacteria in the absence of oxygen to produce biogas and CO₂ and (ii) *fermentation* in which starch/sugar is fermented by yeast and bacteria to produce ethanol

In thermochemical conversion, heat is introduced to transform bio-matters in biomass into different products such as steam, combustible gas, oil and charcoal. Thermochemical conversion is categorized into (i) pyrolysis, (ii) gasification and (iii) direct combustion. This research concerns only electricity generation from biomass via thermochemical conversion, therefore, the following part will discuss on the three main routes of thermochemical conversion.

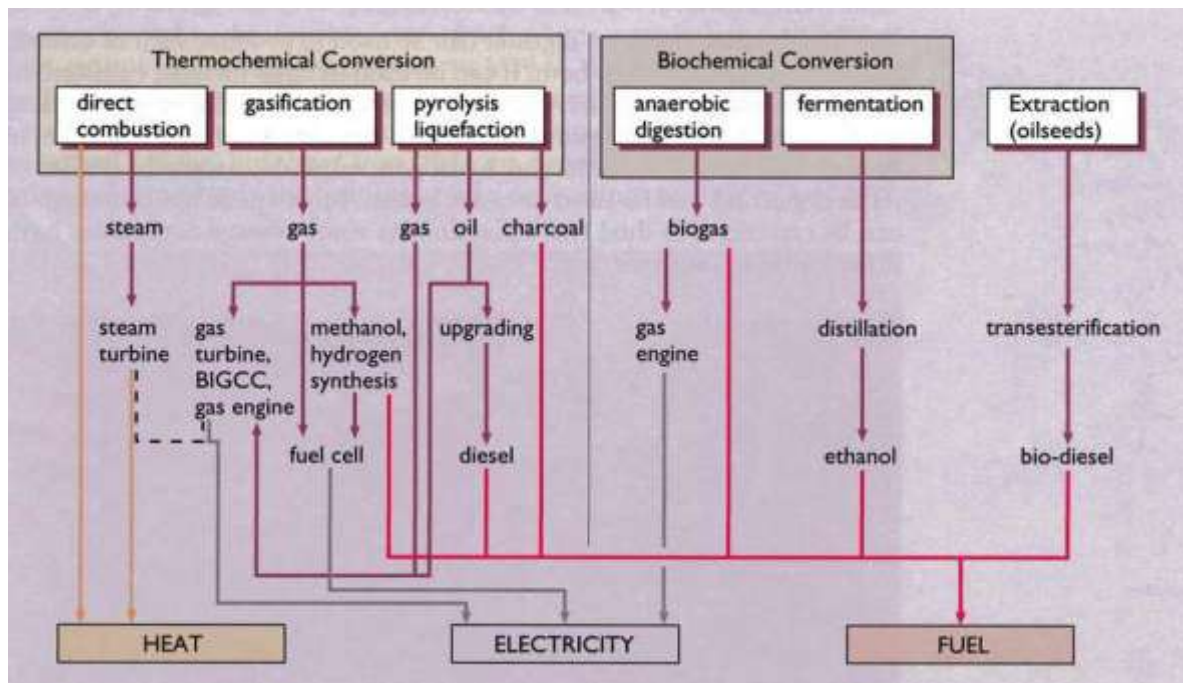


Figure 4. Main bioenergy conversion routes (Boyle 2004)

Gasification

Gasification is the production of a gaseous fuel from a solid fuel. It consists a complex thermal and chemical conversion of organic materials at high temperature under restricted air supply. It occurs at very high temperature, typically between 750 - 1200°C with very little oxygen. Products of gasification include synthetic gas, or syngas, and ash (Kerlero de Rosbo and de Bussy 2012). Syngas is a mixture of combustible gases (carbon monoxide, hydrogen and methane) and incombustible gases (carbon dioxide, nitrogen and other gases). The combustible syngas can be used for electricity generation.

Biomass gasification was introduced in Vietnam since the early 1980s when there was a shortage of petroleum and power at that time. Rice husk gasification combined with power generation was developed in the Southern part of Vietnam in 1980s with 15 systems of 75MW in total installed capacity (D. C. Nguyen 2011). However, due to the improvement in petroleum and power supply and rice husk was then used as fuel in brick and pottery kilns instead, gasification of biomass was neglected. Recently, this technology is getting back the attention of researchers as well as investors. Nevertheless, biomass gasification in Vietnam is still remaining in study stage and no demonstration has been made.

Pyrolysis

Pyrolysis is the thermal degradation of organic material within biomass at a moderate temperature (350 to 600°C) in the absence of oxygen (Kerlero de Rosbo and de Bussy 2012). The products of pyrolysis process consist of charcoal, condensable pyrolysis oils (heavy aromatic and hydrocarbons), tar and condensable gases. The gases and pyrolysis oil can be used as fuel to produce electricity.

In Vietnam, pyrolysis is used to make charcoal in household scale. Previously, the charcoal was produced in traditional kiln, which emit a lot of air-borne pollutants. Recently, the new pyrolysis systems (Figure 5), with significantly lower emission, have become more popular in charcoal production.



Figure 5. Pyrolysis equipment for household scale in Binh Duong (left) and charcoal product (right) (Biomass Energy Team 2014)

Direct combustion

In direct combustion, biomass is burned with the present of oxygen to generate heat, water and carbon dioxide. Hot flue gases are used to heat process water to steam, which drives a turbine, typically via a Rankine cycle (Evans, Strezov, and Evans 2010).

In Vietnam, direct combustion is a method that widely used in both domestic and industrial scale to convert biomass in to heat and power. Most biomass in Vietnam is being used by small rural industries because biomass source is scattered. These small industries use biomass as a heat source for food processing, drying processing or producing building materials such as bricks, tiles, pottery (Figure 6). The total amount of biomass used for heat generation by these users is 3.33 million ton per year, account for 24% of total biomass consumption (D. C. Nguyen 2011). The biomass feedstock used is either raw materials or processed material, such as biomass pellets or briquettes. At industrial scale, biomass direct combustion is mostly for heat production purposes in beer making, textile and food processing factories. In sugar production, the majority of bagasse derived from pressing sugarcane is directly burned in boilers to generate steam, which then be used to produce electricity via a steam turbine.



Figure 6. Rice husk burning in a kiln in Thuan Thoi village (Photo by Arvo Leinonen) (Leinonen and Nguyen 2013)

3.2. Biomass co-firing technologies and application

3.2.1. Co-firing technologies

Biomass co-firing is the technology that consists of burning biomass along with coal in coal-fired power plants. The concept of this technology is to utilize the biomass resources to generate electricity and to reduce the use of fossil fuel as well as the greenhouse gases emission in the coal power plants. This is an approach to drive the coal power plants to less pollution and more sustainable direction with the relatively modest incremental investment. The advantages of biomass co-firing with coal includes carbon dioxide emission reduction, coal consumption reduction, SO₂ emission reduction and no need continuous biomass supply. Nevertheless, there are some concerns related to biomass co-firing such as equipment erosion caused by ashes, high biomass co-firing ratio can reduce power output, biomass supply, storage and handling and possible N₂O emission from biomass storage (Tillman 2000)(IRENA 2014). The possibility of emission reduction depends on type of biomass, how the biomass is obtained, handle, transport and storage.

The available technologies for biomass co-firing include: (i) direct co-firing using a single boiler with either blending biomass together with coal or milling biomass separately then inject directly to the burner (Figure 7); (ii) indirect co-firing with a gasifier (Figure 9) which converts biomass into synthetic gas (or syngas) that fed the burner; and (iii) parallel co-firing (Figure 11) in which a separate boiler is used for biomass and the generated steam is then mixed with steam from coal boiler (IRENA 2013).

Direct co-firing

Direct co-firing is the simplest, cheapest and most common option. Biomass can be milled together with coal (co-feed) or pre-milled and then injected directly into the boiler with separate injector (separate feed) (see Figure 7). With biomass and coal blend, the percentage of biomass introduced is quite low (less than 5% in pulverized boiler and up to 20% in fluidized bed boiler) and the type of biomass used is limited (Tillman 2000). Pulverized coal (PC) and Fluidized bed (FB) are the most used technologies in coal power plant. In PC boiler, coal is ground into very small particles which are then blown into the combustion chamber. With PC, particle size and moisture content is strictly controlled (moisture content lower than 15% and particle size smaller than 15mm) (UNEP 2007). FB boiler consists of a bed of inert material (limestone and sand). Pressurized air is blown from below that causes the bed particle behave like a fluid. FB boiler allows to burn different fuels without affecting performance and to introduce chemical reactant to remove pollutant. FB can burn wood with moisture content up to 55% (UNEP 2007).

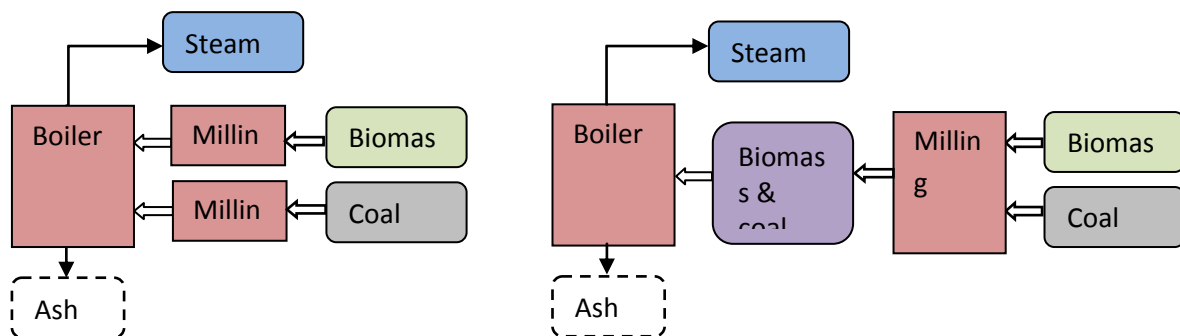


Figure 7. Simplified schemes of co-feed direct co-firing (left) and separate injection direct co-firing (right) (Maciejewska et al. 2006)



Figure 8. Biomass storage and transport at Drax Power Plant, United Kingdom (Alstom 2012)

The cost for plant retrofit range from 300-700 USD/kW for co-feed plants to 760-900 USD/kW for separate feed plants as shown in Table 4 (IRENA 2013). This investment cost is much lower in comparison to that of dedicated biomass power plants because this technology can take advantage of pre-existing large coal-fired power plants and related infrastructures. The operation and maintenance (O&M) cost is around 2.5-3.5% of total capital cost which is similar to that of coal power plant. Therefore, direct co-firing is the most applied technology for biomass co-firing in coal power plants. The biggest biomass co-firing power plant in the world, Drax Power Plant in United Kingdom, is using direct co-firing to burn wood pellets together with coal (Figure 8).

Indirect co-firing

This technology consists of a gasifier to convert the solid biomass into combustible gas, which is then burned with coal in the same coal boiler (see Figure 9). This technology allows much higher co-firing ratios and greater variety of biomass to be used than direct co-firing. In this process, gas cleaning and filtering system is needed to remove gas impurities before injected into coal boiler. Because of the additional technical equipments (gasifier, gas cleaning and filtering), the investment cost for indirect co-firing is much more than that of direct co-firing (see table 4). The O&M cost for indirect co-firing plants is also two times higher than for direct co-firing plant, which is 5% of the total capital cost. An example of indirect co-firing plant is Zeltweg Power Station in Austria (Figure 10).

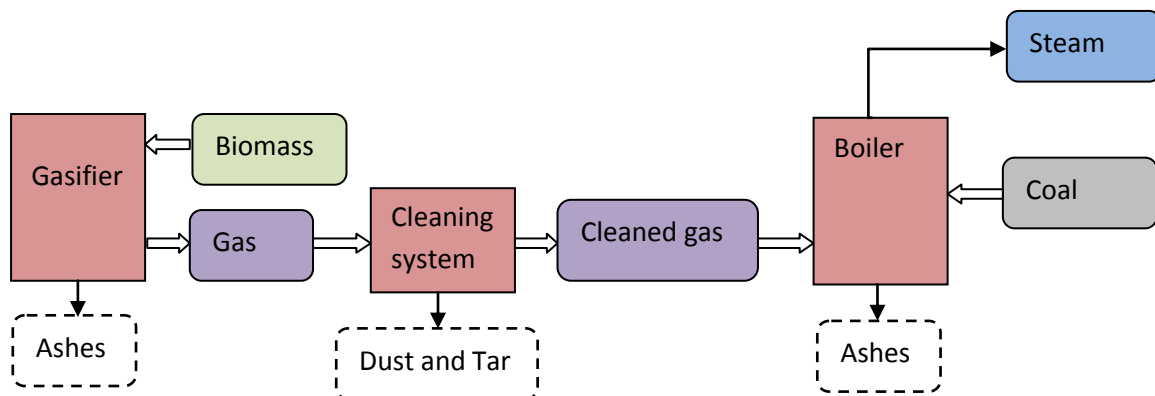


Figure 9. Simplified process layout of indirect co-firing (Maciejewska et al. 2006)



Figure 10. Zeltweg Power Station, Austria (industcards 2012)

Parallel co-firing

In this option, biomass is combusted in a separate boiler. The generated steam is then added into the existing steam cycle from coal boiler to produce electricity. In this technology, biomass preparation and feeding are independent from coal, thus the biomass and coal ashes are separated. (see Figure 11) Because biomass and coal are combusted in different units, the optimal efficiency of each fuel can be chosen. With parallel co-firing, the range of biomass type that can be used is wider and the co-firing ratio is also higher than in direct co-firing. However, the investment cost for installation of parallel co-firing system is significantly higher (IRENA 2014). Parallel co-firing is mostly applied in pulp and paper industrial power plants (Maciejewska et al. 2006). However, there are still several biomass co-firing power plants with parallel co-firing system in operation, one of them is Enstedværket Power Plant in Denmark (Figure 12) (Nikolaisen et al. 1998).

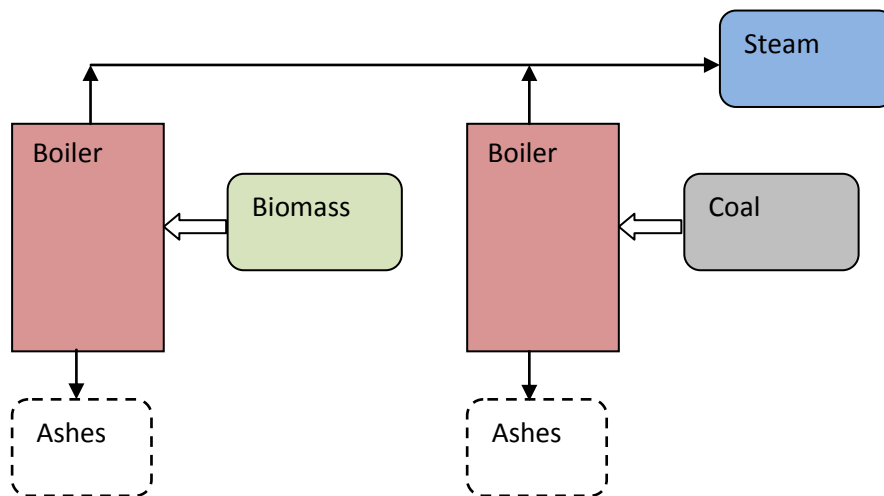


Figure 11. Simplified diagram of parallel co-firing technology (Maciejewska et al. 2006)



Figure 12. Straw bales in feeding line at Enstedværket Power Plant, Denmark

	Direct combustion		Indirect combustion (gasification based co-firing)	Parallel co- firing
	Blend coal with biomass	Separate injection		
Technical description	Mix and grind coal with biomass before injection to furnace	Grind biomass separately then injected to furnace with separate injector	Separate gasification unit	Separate boiler for biomass Mixed steam
Characteristic	Low % of biomass, <5% in pulverized boiler and up to 20% in cyclone boiler(Tillman 2000) Limited type of biomass	Higher biomass % Biomass particle size is important (<3mm)	Wide range of biomass type can be used Possible to use in coal, oil and gas power plant	Wide range of biomass type can be used
Investment cost	USD 300 - 700/kW	USD 760 - 900/kW	USD 3000 – 4000/kW	

Table 4. Summary on co-firing technologies (IRENA 2014)

3.2.2. Experiences in co-firing

Among these technologies, direct co-firing is the most used option due to the low investment cost for converting existing coal power plants into co-firing plants. By 2012, about 230 CHP plants use co-firing, mostly in northern Europe and the United States with the capacity of 50-700 MW_e (IRENA 2013). The list of countries (with number of projects indicated in the parenthesis) that applying co-firing technologies in coal power plants in Europe include the United Kingdom (16), Germany (15), Netherlands (8), Denmark (5), Finland (14), Belgium (5), Austria (5), Sweden (9), Hungary (5), Italy (3) and Spain (1) (EUBIA 2015). The coal fired technologies of these plants cover pulverized coal technologies and fluidized bed technologies. The co-firing technologies applied range from direct/indirect to parallel co-firing.

Europe

Direct co-firing. Many large scale biomass co-firing project are being operated which use direct co-firing technology, including the world largest co-firing plant in the United Kingdom. The Drax co-firing project has the total capacity of the station of 4000 MW, in which, the share of biomass is 10% of heat input, equivalence to 400 MW of output power. This plant applies the direct co-firing technology using wood pellet as biomass feedstock for Pulverized Coal boiler (Henderson 2015). With the huge quantity of biomass needed for co-firing, Drax is going to build two pellet plants in the United States and an associated port for biomass supply chain. The first of six units was converted in 2013. The CO₂ emission reduction is estimated at 2 million tons per year (Henderson 2015).

The Fiddlers Ferry power plant, also in United Kingdom, has two 500 MW_e units, which converted to 20% thermal biomass co-firing. It has a dedicated co-firing system and operated since 2006. The biomass used includes wood pellets, palm kernels, olive stones and olive cake with the moisture content lower than 15% (Henderson 2015).

Indirect co-firing is applied in Zeltweg coal power plant, Austria with the capacity of coal boiler is 137MW. There is a 10 MW gasifier to convert solid biomass (bark and wood chip) into fuel gas (Granatstein 2002).

Parallel co-firing is used at Enstedvaerket power plant – Abenraa, Denmark. The capacity of coal-fired unit is 660 MW_e, and the biomass boiler has capacity of 40 MW_e which is fed with straw (Brem 2005).

United States

Over 40 plants have applied biomass co-firing technology (Baxter 2004). The biomass used includes residues, energy crops and wood with the percentage of co-firing range from 1 to 20%. For example, the Greenidge Generating Station applied separate injection technology to co-fire wood waste with coal in a 105 MW_e boiler with 5-10 percent (heat input basis) of biomass co-firing rate.

Asia

In Japan, there are several pilot tests and proposed projects on co-firing biomass with coal. In Nippon Steel Corporation experimental co-firing started in November 2010 with biomass percentage of 2%. Three Japanese companies that announced to adopt biomass co-firing technology include Hitachi Kyodo Karyoku Co., Ltd, Hokkaido Electric Power Co.,Inc and Ube Industries Ltd (Asia Biomass Office 2015).

4. Feasibility and Sustainability indicators

4.1. Research method

The study was based on literature review, interview with experts in the related field and field study to collect data. A set of indicators is then constructed to assess the preliminary feasibility of applying biomass co-firing technology in coal power plant in Vietnam and the sustainability of such application. The study is conducted following the steps provided in Figure 13.

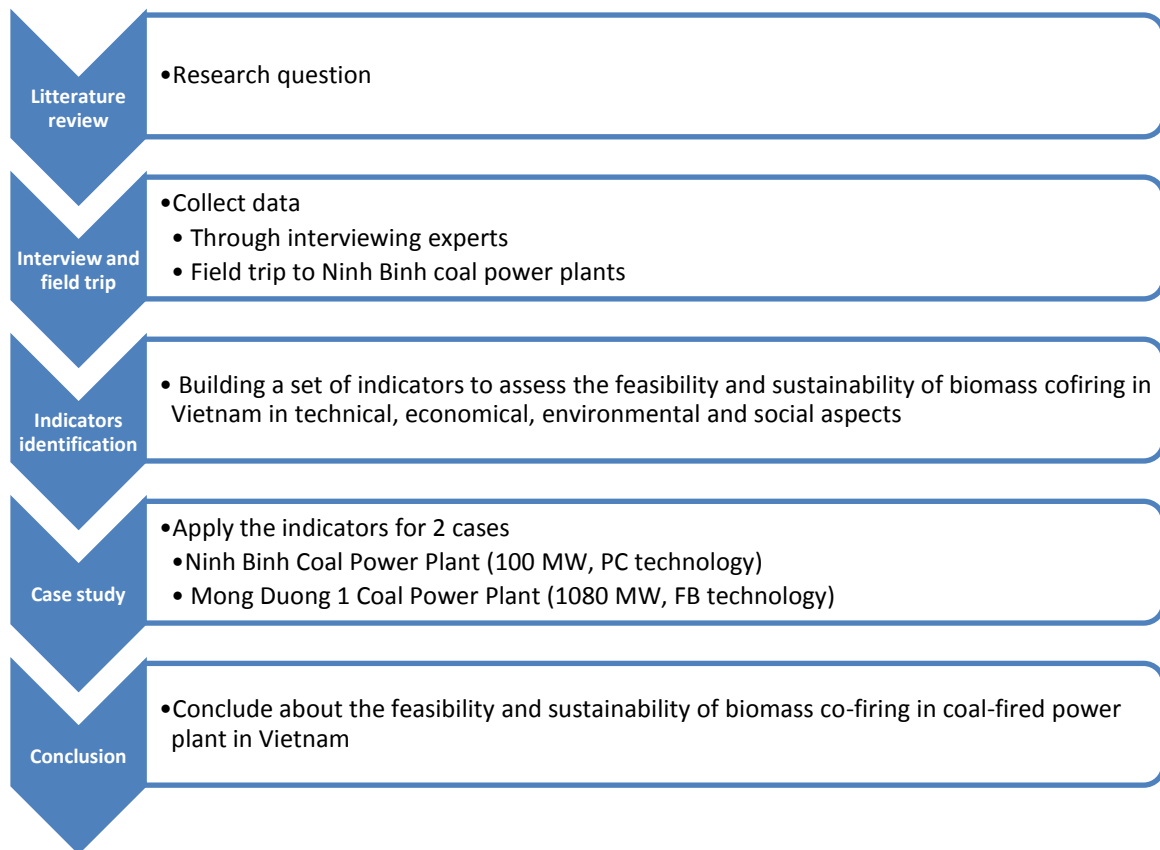


Figure 13. Research steps

Interview and field trip

In order to collect information and data for the analysis, several interviews have been made. The interviewed people include expert in biomass in Vietnam in USAid, expert in biomass fuel chain and energy from biomass in Institute of Energy, engineer in Ninh Binh Coal Power Plant, expert in electricity generation in GENCO 3. The data for Mong Duong 1 Coal Power Plant (CPP) is obtained through the interview.

The field trip to Ninh Binh Coal Power Plant was conducted on March 19th, 2015. The activities consist of interviews and site observation.

Building a set of indicators

To evaluate the feasibility and sustainability of a bioenergy system, it is necessary to have a set of indicators. The effective indicators will help to quantify the costs and benefits of certain

technological option and resource use. The data and information collected from literature review, interviews and field trip then becomes the input for constructing a set of indicators to assess the feasibility and sustainability of biomass co-firing in Vietnam in four categories: technical, economical, environmental and social aspects.

Case study

Two coal power plants were chosen for the case study, Ninh Binh Coal Power Plant and Mong Duong 1 Coal Power Plants. These plants are selected because they represent different installed capacity, technologies and year of operation. Ninh Binh Power Plant is located in Ninh Binh province in Red River Delta with the capacity of 100MW which used Pulverized Coal technology. This plant has operated since 1974. Mong Duong 1, on the other hand, is a recent constructed plant in Quang Ninh province which operated in January 2015. It has the capacity of 1000 MW and applied Fluidized Bed technology.

The result of previous analysis is applied to the two cases to evaluate the feasibility and sustainability of biomass co-firing in each case to conclude whether biomass co-firing with coal in coal-fired power plant is possible and it will contribute to the sustainable development of energy sector in Vietnam, including greenhouse gas emission reduction.

4.2. Determination of indicators

The set of indicators is selected for assessing the feasibility and sustainability of biomass co-firing in the context of Vietnam.

These indicators should be applicable for different types of biomass feedstock that can be used in co-firing. In Vietnam, the agricultural and forestry residue is abundant and the exploitation of these biomass sources is still under their potential. Moreover, the surplus of some agricultural residues such as rice straw remains as an environmental issue. In addition, dedicated biomass fuel crop in Vietnam is not yet developed and there are many social and environmental concerns. Thus, within this study, the indicators were selected to apply for different kinds of agricultural and forestry residues and not for fuel crops. Therefore, the set of indicators does not include the one that related to dedicated bioenergy crops and not so relevant to residue and co-firing such as land use, food security, water use, soil quality and biodiversity.

These indicators should also be useful for diverse stakeholders such as policymakers, investor, farmers and suppliers and so on. For example, policymakers may focus on sustainability of the whole process, investor may interested in the profitability of adopting co-firing technology in their plants and farmers may concerns about the income.

The selected indicators are summarized in Table 5.

	Indicator	Unit
Technical aspect	Overall efficiency with cofiring	%
	Biomass needed	ton/year
	Biomass available density	ton/km ² ·yr
	Collection radius	km
Economical aspect	Biomass unit cost as delivered at the plant	USD/ton
	Total biomass cost/year	USD/year
	Levelized cost of electricity	USD/kWh
	Net Present Value	USD
	Fuel cost saved	USD/year
	Extra revenue for coal export	USD/year
Environmental aspect	GHG emission reduction	ton CO ₂ e/yr
	Local air quality (NO _x , SO ₂ , PM _{2.5} , PM ₁₀)	mg/MJ
	Resource conservation	ton of coal/year
Social aspect	Extra income for farmer	USD/ha
	Number of jobs created per year	FTE jobs/ year

Table 5. List of indicators

4.2.1. Technical aspect

Impact of biomass co-firing to boiler's efficiency and overall efficiency

Biomass co-firing does not reduce the total energy input requirement of the boiler. However, biomass co-firing can affect boiler efficiency. This impact depends principally on the biomass moisture content and the co-firing ratio (Van Loo and Koppejan 2008). With low percentage of biomass (3-5%) the impact to boiler efficiency is moderate. The efficiency loss (EL) of boiler from biomass co-firing can be estimated based on the result obtained by pilot plant test as a function of biomass co-firing ratio (De and Assadi 2009), which expressed by Equation 1 (De and Assadi 2009).

Equation 1

$$EL = 0.0044 \times \text{biomass cofiring ratio}^2 + 0.0055$$

The overall efficiency (η_0) of a plant can be seen as the combination of two efficiency terms, boiler efficiency (η_b) and the rest power efficiency (η_{rp}). Then

Equation 2

$$\eta_0 = \eta_b \times \eta_{rp}$$

In case of biomass co-firing, the new boiler efficiency is reduced by the amount of efficiency loss, therefore, the plant efficiency after retrofitting for biomass co-firing ($\eta_{0,bm}$) can be calculated as

$$\eta_{0,bm} = (\eta_b - EL) \times \eta_{rp}$$

The calculation of efficiency loss based on biomass co-firing ratio is provided in Table 6. Comparing to the range of the boiler efficiency (from 82% to 89%) and the overall efficiency (from 21% to 36%) of coal power plants in Vietnam (Institute of Energy-MOIT 2014), biomass co-firing does not significantly reduce the efficiency of the boiler or the plant.

Biomass cofiring ratio	Efficiency loss
0.03	0.55%
0.05	0.55%
0.10	0.55%
0.15	0.56%
0.20	0.57%

Table 6. The efficiency loss of boiler due to co-firing

Biomass required for co-firing in a plant

The amount of biomass required for co-firing in a certain coal-fired power plant depends on the biomass co-firing ratio and heat value of the biomass used. To calculate the required amount of biomass, an assumption has been made, in which the gross heat input to the boiler remains the same for coal fired only (before retrofitting) and for biomass co-fired (after retrofitting) condition.

The amount of biomass needed for biomass co-firing per year is calculated by Equation 4.

$$\text{Biomass required} = \frac{[\text{Gross Heat input} \times \text{biomass cofired ratio}]}{\text{Heat value of biomass}}$$

Where Gross heat input is expressed in MJ, heat value of biomass is in MJ/kg and biomass required is in kg.

The required gross heat input calculated based on Equation 5

$$\text{Gross Heat input} = \frac{\text{Annual power generation}}{\eta_{0,bm}} \times 3.6$$

Where the annual power generation of the plant is expressed in kWh, $\eta_{0,bm}$ is the overall efficiency of the plant with co-firing and 3.6 is the coefficient to convert kWh into MJ.

With the result on total biomass needed for co-firing in a plant, then the number of trucks or boats required for supplying biomass to the plant per day can also be estimated by Equation 6, knowing the load of each truck or boat. This is an average number, assuming that the plant need the same amount of biomass delivered every day.

$$\text{Number of truck per day} = \frac{\text{Biomass required}}{365 \times \text{truck load}}$$

Available amount of biomass for co-firing

One of the most key importance factors that impact directly to the technical feasibility of biomass co-firing is the actual amount of biomass feedstock that is available for the coal power plant. As discussed in Chapter 2, the total theoretical potential of electricity generation from biomass could reach 123 TWh (Table 2). However, the practical potential is much lower than this since not all agriculture residues produced are available for power generation. This due to the fact that only a part of biomass produced is collected, of which a portion can be used for other purposes rather than producing electricity.

This study consider only the agricultural residues as the feedstock biomass co-firing, since agricultural residue in Vietnam is abundant and the unused amount of residue might pose environmental thread (for example, most of the rice straw is burn in the field after harvest season that cause air pollution) (Leinonen and Nguyen 2013).

Therefore, the amount of biomass (agricultural residue) produced per year is calculated based on the Residue to Product Ratio (RPR) as showed in Equation 7. The RPR of some agricultural residue is provided in Table 7.

$$\text{Biomass produced} = \text{agricultural production} \times \text{RPR of biomass}$$

Biomass	Residue to Product Ratio (RPR)
Rice husk	0.2:1
Rice straw	1:1
Corn residue	2.5:1
Bagasse	0.3:1
Coffee husk	0.3:1
Coconut shell	0.15:1

Table 7. RPR of some agriculture residue

Biomass available density

The biomass available density (D) is the amount of biomass available per area per year. The biomass available density is calculated by equation 8.

$$D = Y \times F_d \times F_c \times F_s$$

Where Y is the biomass yield in ton per square kilometers-year, F_d is the biomass planted area density (the ratio between planted area and total land area), F_c is the collection fraction which referred to the percentage of biomass collected and F_s is the selling proportion which referred to the percentage of not used biomass. The biomass yield is calculated based on the crop production and

RPR. The data on crop production is taken from Vietnam Statistical Yearbook 2014 published by General Statistic Office of Vietnam.

The percentage of biomass collected and available for selling to the plant is taken from the data in the previous study (Tran 2011) and listed in Table 8.

Crop residues	Total biomass produced	Biomass collected	Biomass utilized	% biomass collected	% of biomass available (unused)
	Million ton	Million ton	Million ton	F _c	F _s
Rice straw	37.57	18.8	7.8	82%	79%
Rice husk	7.52	4.5	3	64%	60%
Bagasse	7.20	5.9	4.3	68%	40%
Other crop residue	20.4	13.1	8.5	42%	58%

Table 8. Amount and percentage of biomass used over total biomass produced

4.2.2. Economic aspect

Up to now, there is no particular regulation for the development of biomass co-firing in the country because this is a brand new concept of utilizing biomass in Vietnam. In Decision 24/2014/QD-TTTg of the Prime Minister on the supporting mechanism for the development of electricity from biomass projects, several mechanisms has been established, including the incentives from capital mobilization, taxes, land use, selling electricity and power tariff. However, in this Decision, the biomass power project is defined as the plants that mostly use biomass to generate electricity. Based on this definition, biomass co-firing power plant with only small percentage of biomass used might not be categorized as biomass power project to get all the incentives that are mentioned. Therefore, all the following calculation will take the input data such as taxes and power tariff without incentive for biomass power project. All the present price and cost in Vietnam Dong are converted into USD using the current exchange rate at 21,473 VND per USD as on July 24th 2015 (State Bank of Vietnam 2015).

Biomass unit cost

Biomass cost varies greatly on the type of biomass (dedicated energy crops or agriculture and forestry waste), the way biomass is collected and the transportation distance from delivery point to the plant.

In this study, biomass cost is broken down into two components, the fixed cost of the feedstock (BC_{fix}) at the field and the cost of transportation (BC_{tran}). Thus, the total biomass unit cost in USD per ton is estimated by Equation 9.

Equation 9

$$BC_{total} = BC_{fix} + BC_{tran}$$

To calculate the transportation cost, a simple model is applied using the transportation cost per unit weight distance (Tr_t) and the assumption where biomass is collected within a circular with the plant at the center. The average cost of transportation can be calculated by Equation 10 (Diep 2014).

Equation 10

$$BC_{tran} = \frac{2}{3} \times R \times \tau \times Tr_t$$

Where R is the radius of collection area (km), τ is the tortuosity factor (ratio of the actual distance travelled in a straight-line distance). τ receives the value from 1.27 for developed agricultural regions to 3.0 for poorly developed regions (Diep 2014). In this study, it is assumed that $\tau = 1.5$ for the case of Vietnam (Diep 2014). Another assumption is that the fixed cost of feedstock is the same for any delivery point within the area of collection. The radius of collection area is calculated based on the amount of biomass required for co-firing and biomass available density. R reflects the minimum distance from the plant which marks the area that can adequately supply biomass to the plant. As the collection area is calculated by the following equation,

Equation 11

$$Collection\ area = \pi R^2 = \frac{Biomass\ required}{Biomass\ available\ density}$$

then, R is calculated as

Equation 12

$$R = \sqrt{\frac{Biomass\ required}{Biomass\ available\ density} \times \frac{1}{\pi}}$$

Fuel cost saving

Fuel cost saving is the avoided cost when the plant uses biomass to substitute part of coal. Fuel cost reduction is calculated by the difference between the cost of biomass used and the cost of substituted coal as in Equation 13.

Equation 13

$$FC_{saved} = (Coal\ saved \times Coal\ price) - (BM_{use} \times Biomass\ price)$$

Where FC_{saved} is the fuel cost avoided by co-firing biomass in dollars per year (USD/year), Coal saved is the amount of coal substituted by biomass in ton per year, coal price in dollars per ton (USD/ton), BM_{use} is the amount of biomass used for co-firing in ton per year and biomass price is in dollars per ton (USD/ton). This study uses the coal price of coal for power plants as published by Ministry of Industry and Trade (MOIT 2015) as summarized in Table 11.

Fuel cost reduction depends on the cost of biomass as well as the coal price. As coal price will continue to rise up, to increase the amount of fuel cost savings, it is important to obtain the biomass fuel as a low price. Creating a biomass market for electricity generation and an efficient biomass supply chain could be a way to reduce biomass price. Subsidies for biomass price for power generation could also help in lowering feedstock cost for co-firing.

Levelized cost of electricity

The levelized cost of electricity (LCOE) is the constant unit cost (per kWh or MWh) of a payment stream that has the same present value as the total cost of building and operating a power plant over its life. In this study, the sLCOE, the minimum price at which energy must be sold for an energy project to break even (or have present value of zero), will be calculated by Equation 14 (NREL 2015).

Equation 14

$$LCOE = \frac{\text{capital cost} \times CRF + OM_{fix}}{8760 \times \text{capacity factor}} + \text{fuel cost} \times \text{Heat rate} + OM_{var}$$

Where capital cost is measured in dollars per installed kilowatt (USD/kW) of biomass power basis (not per kW of total power of the plant), fixed O&M cost (OM_{fix}) in dollar per kilowatt-year and variable O&M cost (OM_{var}) in dollars per kWh.

The sLCOE is calculated just for the electricity generated from biomass co-firing and not for the whole electricity production of the plant. This indicator gives an overview on the price to generate 1kWh of electricity through biomass co-firing. Thus, all the input parameters such as installed capacity, capital cost, fuel cost, operation and maintenance cost, electricity output are for biomass co-firing only as a marginal (additional) project.

The capital cost depends on the co-firing technology, boiler type and percentage of biomass co-fired. Direct co-firing with biomass and coal blend has the lowest capital cost, while indirect co-firing with gasifier is the most expensive one. For boiler type, co-firing in Fluidized bed boiler costs less than co-firing with pulverized coal boiler. Moreover, the capital cost goes higher when higher percentage of biomass co-fired is applied. For example, the unit capital cost for 15% biomass co-firing in fluidized bed boiler is estimated at 50 USD/kW while for the same biomass co-firing percentage in pulverized coal boiler, this can be as high as 230 USD/kW (Hayter and Tanner 2004). However, with lower biomass percentage (3%), the unit capital cost for co-firing in pulverized coal boiler can be at 100 USD/kW. It should be noted that these costs are expressed per unit of power capacity on biomass combustion, not on total installed capacity of the power plant. For example, at 5% co-firing rate (heat basis) in a 100 MW coal power plant, the power capacity on biomass combustion is 5 MW, and the capital cost is then calculated only for 5 MW capacity of biomass not for the 100 MW capacity of the plant.

Capacity factor is calculated by the ratio of annual power generation over the theoretical power generation if the plant operates 24 hours per day for all days of the year. Fuel cost is in dollar per mega joule (USD/MJ) and heat rate is in MJ per kWh (MJ/kWh). Heat rate is the amount of input heat to produce 1kWh of electricity. It depends on the overall efficiency of the plant. The constant 8760 is the number of hours in a year.

CRF, the capital recovery factor, is calculated by Equation 15 with a discount rate i . The discount rate is based on market interest rate or weighted average cost of capital. In this study, the discount rate i is referred to Weighted Average Cost of Capital (WACC) is selected to be the discount rate (GIZ/MOIT 2014). n is the analysis duration, which is equivalence to the plant life time. In this calculation, n is taken as 20 years (GIZ/MOIT 2014).

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1}$$

WACC is calculated at 8.78% and the Capital recovery factor is 0.11.

Net Present Value

Net Present Value (NPV) is used in this study to evaluate the economic viability of biomass co-firing (Lüschen and Madlener 2012). The general equation for NPV calculation is as below (Dale et al. 2013).

$$NPV = \sum_{t=0}^n \frac{C_t}{(1+i)^t}$$

Where C_t is the net cash flow at time t ; t is the time of cash flow; i is the discount rate. If the NPV is less than zero then the project is not profitable, while with a positive NPV, the project is profitable. The profitability becomes higher when NVP increases.

In this section, NPV is calculated from the net cash flows, which is the difference between the cash inflows and outflows. The cash inflow is the electricity sales revenue, calculated by the electricity sales in kWh multiply by the electricity tariff in USD per kWh. The cash outflows include total capital cost, fuel cost, O&M cost and income tax. Since the NPV is calculated for biomass co-firing, all the input parameters such as total capital cost, electricity sale and fuel cost are for the biomass co-firing only.

In this calculation, the electricity tariff is taken as 0.054 USD/kWh, which is the tariff for electricity sale from the power plants that joined the competitive market published by the Ministry of Industry and Trade (MOIT 2015). Fuel cost and capital cost are referred to the calculation above. The analysis period is 20 years and the discount rate is WACC as stated in the LCOE calculation section. Income tax rate is 25% as stipulated in Corporate Income Tax Law.

4.2.3. Environmental aspect

GHG emission

In this section, greenhouse gas emission (in ton CO₂ equivalence) is estimated for biomass co-firing and coal firing only to have the overview on emission reduction if co-firing is adopted in the coal power plant. The boundary for GHG emission calculation is restricted within biomass/coal transportation and biomass/coal combustion. This is based on the assumption that the rice production and coal mining remain the same with or without biomass co-firing. Therefore, the total emission of biomass co-firing and coal-only scenarios is estimated by Equation 17.

$$\text{Total GHG emission} = \text{Emission from transportation} + \text{Emission from combustion}$$

The emission from fuel combustion is calculated with Equation 18 (IPCC 2006).

Equation 18

$$\text{Emission from combustion} = \text{Emission factor of fuel combustion} \times \text{fuel consumption}$$

The default GHG emission factors for stationary combustion of different types of coal in energy industry are taken from chapter 2 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, which summary in the Table 9 below (IPCC 2006). The emission factor of rice straw is referred to a previous study (Shafie, Mahlia, and Masjuki 2013).

Fuel type	Emission factor by greenhouse gases (kg of greenhouse gas per TJ)			Emission Factor in ton CO ₂ e*/TJ	Emission Factor in ton CO ₂ e/MJ
	CO ₂	CH ₄	N ₂ O		
Anthracite	93,000	1	1.5	98,786	0.0988
Coking coal	94,600	1	1.5	95,086	0.0951
Other bituminous coal	94,600	1	1.5	95,086	0.0951
Sub-bituminous coal	96,100	1	1.5	96,586	0.0966
Lignite	101,000	1	1.5	101,486	0.1015
Wood/wood waste	112,000	30	4	113,870	0.1139
Rice straw	83,840	9.03	5.59	85,763	0.0858

Table 9. GHG emission factors by type of fuel in stationary combustion

* The CO₂ equivalence is calculated based on the greenhouse effect potential of CH₄ and N₂O which is 21 and 310 times more than CO₂

The emission from transportation based on the transportation distance (km), transportation emission factor (kgCO₂e/ton.km) and total amount of transported matter (ton) by the following Equation (Alberici and Hamelinck 2010).

Equation 19

$$\text{Emission from transportation} = \text{Distance} \times \text{emission factor} \times \text{total weight transported}$$

The emission factors for some modes of transportation (McKinnon and Piecyk 2010) are listed in the Table 10.

Transport mode	Emission factor (gCO ₂ /ton.km)
Road transportation	62
Rail transportation	22
Barge transportation	31

Table 10. Emission factor of by modes of transportation

Resource conservation

The amount of coal conserved depends on the biomass co-firing percentage and it can be estimated by Equation 20.

Equation 20

$$\text{Coal saved} = \frac{\text{Gross heat input} \times \text{biomas cofiring rate}}{\text{Heat value of coal}}$$

This amount of coal saved by biomass co-firing could be compare with the amount of coal mined per year.

4.2.4. Social aspect

Extra income for farmers

Farmers could earn additional income selling their agricultural residue to the plant for co-firing instead of burning or disposing. This income per ha of cultivation land can be estimated based on the biomass price delivered at the field (USD/ton) and the biomass yield (ton/ha) as in Equation 21.

Equation 21

$$\text{Extra income per ha} = \text{biomass price} \times \text{biomass yield}$$

This amount can be compared to the average annual income of the farmers to see whether is significant or not. Currently, the farmers' income per hectare of cultivation is 3,100 USD/year (Hoa An 2015).

Jobs created from biomass co-firing

Jobs result from biomass co-firing can be categorized into direct jobs, indirect jobs and induced jobs. According to Global Bioenergy Partnership (GBEP) (2011), definition of direct job in bioenergy sector is the job created by the value chain of production and use of bioenergy which include biomass production, collection, transportation, conversion and processing, production of the equipments for the deployment of bioenergy, bioenergy supply and distribution, operation and maintenance of the plant and equipment. Indirect jobs are defined as jobs in other business or industries supplying goods and services to the bioenergy sector. Induced employments are jobs that created when the direct and indirect employees (and their families) use their wages from direct and indirect employments to buy goods and services for their own use.

The jobs created can be measure by number of fulltime equivalence (FTE) jobs per MW (Dale et al. 2013)(GBEP 2011). The FTE job has been defined as a job that occupies employees for at least thirty hours per week (GBEP 2011). This can be estimated from number of working hours per year required by biomass co-firing per MW over the life time of biomass co-firing (Singh and Fehrs 2001). In this study, the scope of the value chain steps require employment in biomass co-firing include biomass feedstock production, biomass transportation, installation of co-firing equipments and operation and maintenance of co-firing equipments. The jobs created can be sorted into permanent jobs (such as fulltime employee in the plant for operation and maintenance) or impermanent/seasonal jobs

(such as jobs in biomass collection for just during harvesting season or jobs during equipment installation).

Extra revenue from coal export

In Vietnam, the price of coal for power generation is currently control by the government since it is one of the most important factors that impact the electricity price.

Vietnam National Coal and Mineral Industry Holdings Limited (VINACOMIN), a state owned entity, is the exclusive coal supplier for power plants. As the coal price is regulated by the government, VINACOMIN claimed that they are selling coal to the power plant with the lower price than the cost of production. In July 2013, after the coal price is adjusted by MOIT, it was still only 85-87% of the production cost in 2013 (VINACOMIN 2013), which means by 2013, VINACOMIN still lost their revenue from selling coal to the power plants. The latest approval of the government for VINACOMIN to adjust the coal price for electricity generation was on 22/7/2014, with the increase from 5% - 7% due to the rise of natural resource tax and production cost. Even with the new price, the coal price is just equal to 86-91% the price for export (Finance News 2014). Therefore, VINACOMIN still lose a significant amount of money from selling coal to the power plant rather than exporting it. With the amount of coal saved from biomass co-firing, VINACOMIN could reduce the amount of coal sell at low price, thus increase the amount for export and earn more revenue from that. It can be estimated that for each ton of coal exported instead of selling to power plant, coal exporter can earn from 9 to 14 USD depends on coal types, assuming the coal price for power plant is 86% of export price. From this we can calculate the amount of revenue from the coal saved from biomass co-firing. The saving from coal import can be estimated via Equation 22.

Equation 22

$$Saving\ from\ import = Coal\ saved \times (coal\ export\ price - coal\ price\ for\ electricity)$$

Coal type	4b	5a	5b	6a	6b
Heat value (kcal/kg)	> 6050	> 5500	> 5500	> 4850	> 4400
Price for electricity generation (VND/ton)	1,800,000	1,606,400	1,376,400	1,276,400	1,131,400
Price for export (VND/ton)	2,093,023	1,867,907	1,600,465	1,484,186	1,315,581

Table 11. Coal price for electricity generation and for export by type

National energy security

As mentioned in chapter 2, the demand for coal in coal power plants will increase in the next decades when the coal power plants listed in the National Power Development Plan VII will be operated. According to the Development plan of coal sector, the amount of coal to be imported for

power generation in 2015 will be 28 million tons, in 2020 will be 66 million tons and will reach 126 million ton in 2025. With biomass co-firing adaptation, the amount of coal saved could help to reduce the amount of coal need to be imported for power generation and thus reduce the foreign currency spend for importing coal.

5. Case study

5.1. Power plants selection for case study

5.1.1. Mong Duong 1 Coal Power Plant

Mong Duong 1 Coal Power Plant is located in Cam Pha district, Quang Ninh Province, northeastern coast of Vietnam (see Figure 14). The plant's installed capacity is 1080 MW with 2 power generation units and the average annual power generation is 6.5 TWh (TTBV 2015). In Mong Duong CPP, Circulating Fluidized Bed (CFB) technology is applied with 2 boilers used for each power generation unit. The first unit is commissioned in January 2015 (TTBV 2015). The technical features of the plant are provided in Table 12.

This plant is selected to be a case study in this research because it is a newly constructed plant with CFB technology. CFB is becoming more popular technology to be applied in coal-fired power plant in Vietnam than Pulverized Coal technology. There are already 5 CFB plants already operated and 6 more CFB plants to be built with total installed capacity of 5,710 MW compare to 3,380 MW of PC plants (Institute of Energy-MOIT 2014). The CFB technology has two major advantages over PB technology: (i) it has higher combustion efficiency for low and widely variable quality fuel, therefore, it can utilize the surplus of low quality coal; (ii) it can reduce the emission of NO_x and SO_x during the combustion process without installing expensive equipments for pollutants treatment. Hence, CFB is now become more favorable technology to be applied in coal-fired power plants in Vietnam (Institute of Energy-MOIT 2014). Furthermore, CFB boilers can maintain the efficiency and flexibility when using difference fuels as designed, thus create a chance to use non-traditional fuel such as biomass (Institute of Energy-MOIT 2014). Therefore, a CFB power plant is a good case study for co-firing biomass.

Within the scale of this research, the case study will investigate the feasibility of biomass co-firing in Mong Duong 1 Coal Power Plant with direct and co-feed co-firing technology and 5% of biomass ratio in term of heat content. As discussed in section 2.3, direct co-firing is the most applied technology for biomass co-combustion because of low investment cost and simplest to implement (IRENA 2014). In the context of Vietnam, where the resources for investment in green energy is still limited, focusing on the low cost technology is a better approach. The percentage of biomass co-fired is set at 5% because the majority of co-firing plants is now operating with this ratio. Moreover, low biomass percentage is easier to be co-fed to the boiler and has less impact to the boiler efficiency.

The biomass feedstock selected for this case study is rice residues since the plant is located in Red River Delta, where the most produced agriculture crop is rice. In this case, rice straw is chosen to be the biomass fuel for co-firing because the volume of rice straw produced is much larger than that of rice husk and most of them is currently burned in the field after harvesting, which cause serious air pollution in the area. In this study, the characteristics of rice straw that included in calculation are heat value, which is taken at 11.7 MJ (Leinonen and Nguyen 2013) and the Residue to Product Ratio, which is 1:1.

5.1.2. Ninh Binh Coal Power Plant

Ninh Binh Coal Power Plant is located in Ninh Binh City, Ninh Binh Province in Red River Delta. The plant has total installed capacity of 100 MW with 4 units and average annual electricity generation of 0.75 TWh. This plant use Pulverized Coal technology which adopted from China since the 70s. Ninh Binh CPP is one of the 9 Pulverized Coal thermal power plants in Vietnam. The first unit of Ninh Binh CPP was in operation in 1974 and in 1976 for the second unit. This is one of the oldest CPP in Vietnam together with Uong Bi CPP which commissioned in 1975. Although being operated over 40 years, these plants do not have any plan for shut down in the future. Due to the old technology, the coal consumption for the plant is 0.56 kg/kWh, which is quite high according to the interviewed plant's engineer, thus led to high fuel cost. For that reason, the plant is now testing to substitute partially the anthracite coal that currently used by bituminous coal imported from Indonesia to reduce fuel cost by using lower rank coal. Based on this intention of the plant, Ninh Binh CPP is selected as a case study in this research as a representative of PC coal power plant with small installed capacity to see whether biomass co-firing could be adopted in this plant as a measure of saving fuel cost and providing other benefits.

Similarly to case 1, the co-firing technology selected for Ninh Binh CPP is direct and co-feed biomass with coal with the biomass percentage of 5%. The biomass used for co-firing is also rice straw as Ninh Binh CPP is located in a province where rice is the main agricultural crop.



Figure 14. Geographical location of Ninh Binh and Mong Duong 1 Coal Power Plant

Parameter	Value		Unit
	Mong Duong 1 CPP	Ninh Binh CPP	
Installed capacity	1,080	100	MW
Annual power generation	6,500	750	GWh
Annual coal consumption	2.75	0.42	Mton/year
Heat value of coal	19.4	25.3	MJ/kg
Overall efficiency	38.84	21.77	%
Boiler's efficiency	87.03	81.61	%
Rest efficiency	44.63	26.68	%
Coal transportation method	conveyor belt (the plant located next to the coal mine)	barges	
Load of each shipping	-	2000	ton/shipping
Number of shipping per year	-	210	Shipping/year
Coal transportation distance	5	200	km

Table 12. Technical parameters of Mong Duong 1 Coal Power Plant and Ninh Binh Coal Power Plant

5.2. Indicators calculation

Overall efficiency of the plant with biomass co-firing

With the biomass co-firing ratio of 5%, the overall efficiency of the plant with biomass co-firing is 38.59% for Mong Duong 1 CPP and 21.62% for Ninh Binh CPP. Comparing to the original efficiency, the efficiency loss is 0.25% for the former case and 0.15% for the later. The reduction in efficiency is due to the efficiency loss from biomass combustion in the boiler. As we already assumed that the gross heat input to the boiler remains the same for coal fired only and biomass co-firing, the boiler's efficiency loss only increase the amount of biomass used and will not impact the electricity output of the plant.

Biomass required for co-firing

Using Equation 4, the total amount of rice straw required for 5% co-firing in Mong Duong 1 CPP is estimated at 259,107 ton per year. In this case, an assumption is made, in which, rice straw is transported to the plant by truck with the load of 20 tons. With this assumption, the plant will need

35 trucks delivered to the plant per day. For Ninh Binh CPP, the annual demand for rice straw is at 53,362 ton, which corresponds to 7 trucks delivery each day.

Biomass available density and collection radius

Mong Duong 1 CPP is constructed in Quang Ninh province where there major coal mining activities in Vietnam takes place. This area does not have large rice cultivation area with the rice yield of 4.92ton/ha (GSO 2013). Based on the RPR of rice straw, the total amount of rice straw produced is calculated at 211,400 ton/year. The rice straw available density of Quang Ninh province is estimated by Equation 8 at only 5.49 ton/km²-year with F_a , F_c and F_s are 0.03, 0.5 and 0.79, respectively. Based on the rice cultivation area in Quang Ninh, the total rice straw available is estimated at 95,506ton/year, which is not enough for biomass co-firing in Mong Duong 1 CPP. Therefore, to supply adequate amount of rice straw for co-firing, it is necessary to transport rice straw from the adjacent provinces such as Bac Giang, Hai Duong, Hai Phong.

Because Mong Duong 1 CPP located in a specific spot which is next to the coast line (see Figure 14), the calculation of collection area and radius is different from what described in Equation 11 and 12. The collection area for this case is assumed as half a circle as showed in Figure 15, with the smaller one inside represent the shortest distance from the plant to the border of Quang Ninh with other provinces which is measured at about 50km. Based on this assumption, two equations can be derived to calculate the collection radius for this case (Equation 23 and 24). Where S is the area of the dark ring in km², R is the collection radius; r is the distance from the plant to other province; $D1$ is the rice straw density in Quang Ninh province and $D2$ is the average rice straw density of the adjacent provinces which is 60.38 ton/km²-year. Then, the Collection radius R is calculated at 71km.

Equation 23

$$S = \frac{\pi}{2} \times (R^2 - r^2)$$

Equation 24

$$\text{Biomass required} = S \times D2 + \frac{\pi r^2}{2} \times D1$$

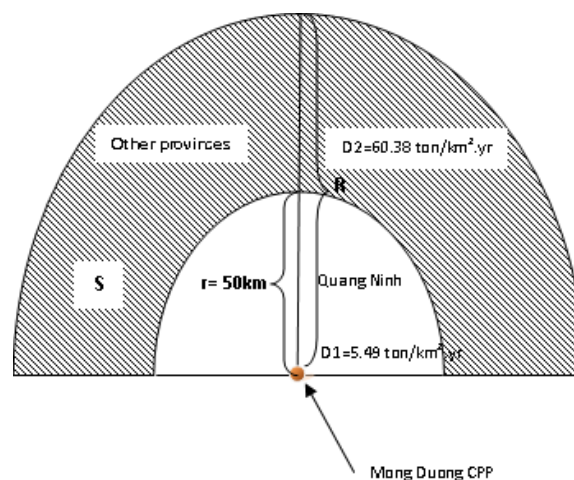


Figure 15. Assumption on rice straw collection area for Mong Duong 1 CPP

The rice straw production Ninh Binh province is estimated based on the rice production taken from the Statistical Yearbook, which is 460,900 ton per year. Compare to the rice straw required of 53,362 ton per year, it is possible that Ninh Binh province can supply enough feedstock for biomass co-firing in Ninh Binh CPP. Therefore, the rice straw density will be calculated using data from Ninh Binh province only.

The rice cultivation area in Ninh Binh province is 41,000 ha over the total area of 137,800 ha. Thus, the rice planted area density (F_d) is 0.30. With the Collection fraction (F_c) and selling proportion (F_s) of rice straw are 0.5 and 0.79 as showed in Table 8. The rice straw density in Ninh Binh province is calculated at 68.67 ton/km²·year using Equation 8. Then the collection area is approximately 777km² as derived from Equation 11. Based on Equation 12, the collection radius is estimated at 16 km.

Biomass unit cost

The transportation cost of rice straw is estimated by using Equation 10 with the biomass col

lection radius for each case is calculated in the previous section and with the transportation tariff of 0.06 USD/ton·km as stipulated by local authorities (Ninh Binh People's Committee 2014). The results of transportation cost for the cases of Mong Duong 1 CPP and Ninh Binh CPP are 4.06 USD/ton and 0.9 USD/ton, respectively.

Rice straw fix cost is estimated by the rice straw bales price sold at the collection point. This includes the collecting and baling cost using rice straw winders. Rice straw is formed into rolls, about 15kg per roll, and sold at 12,000 VND for each roll (Hoang Thai and Giao Linh 2015). This price is equivalence to 0.56 USD per roll, which results in 37.26 USD per ton of straw. With the rice straw fix cost at 37.26 USD/ton applied for both cases, then the total rice straw cost per ton is 41.31 USD for Mong Duong 1 CPP and 38.15 USD for Ninh Binh CPP.

Resource conservation

Due to rice straw co-firing, the amount of coal consumption reduced is estimated at 155,987 ton per year. For Ninh Binh CPP, the coal conserved is 24,664 ton per year. The total amount of coal saving per year of the two cases is approximately 0.5% of total coal production in 2014, which was 37.7 million ton (Pham 2014).

Fuel cost savings

For Mong Duong 1 CPP, the calculation of fuel cost saving based on Equation 13 results in negative value of -2.5 million USD per year, which means the plant would have to spend extra 2.5 million USD on buying biomass for co-firing. This is because the fuel cost per MJ of biomass in this case is higher than that of coal. The cost for each GJ of heat generated from coal is 2.71 USD while the rice straw cost per GJ of heat generated for the case of Mong Duong 1 CPP is 3.53 USD (Figure 16).

On the other hand, co-firing with rice straw in Ninh Binh CPP will help the plant to save 31,533 USD per year from fuel expense. The different result of fuel cost saving of the two cases is due to the biomass cost per GJ heat. For Ninh Binh CPP, this cost is 3.26 USD per GJ, which is lower than 3.31 USD per GJ for coal in this case.

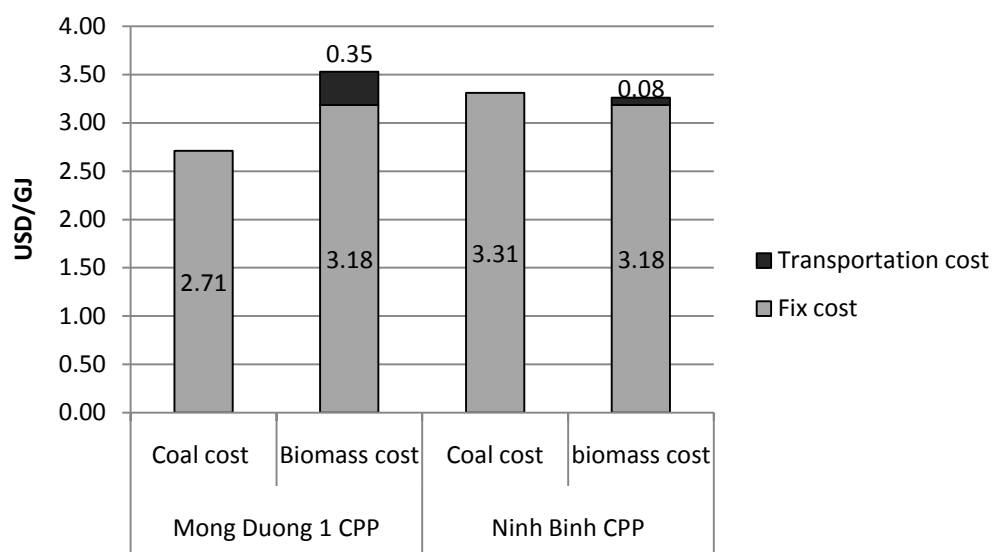


Figure 16. Fuel cost (per GJ heat) breakdown for two cases

Levelized cost of electricity

For Mong Duong 1 CPP, the capital cost per unit is taken at 50 USD per kW of installed capacity of biomass co-firing as for the case of direct co-firing with co-feed in fluidized bed boiler. The Fix O&M and Variable O&M cost are taken at 32.24 USD/kW·year and 0.6 UScent/kWh (Broadman et al. 2013) for both cases. With these and other input parameters mentioned in chapter 4, the LCOE is calculated at 4.5 UScent/kWh by using Equation 14.

In the case of Ninh Binh CPP with pulverized coal technology, the capital cost per unit used in LCOE calculation is 100 USD per kW. Then, the LCOE for Ninh Binh CPP is estimated at 6.6 UScent/kWh. Compare to the tariff at which the coal power plants sell electricity to EVN, the LCOE of Ninh Binh CPP is higher.

Net Present Value

The NVP calculation for biomass co-firing at Mong Duong 1 CPP is 1,848,558 USD. The positive NPV indicates that the investment on co-firing coal with rice straw could bring economical benefit for the plant. The payback period for the investment in biomass co-firing in Mong Duong 1 CPP is estimated at 6.5 years based on the cumulative cash flow.

Meanwhile, the calculation shows a negative Net Present Value for the case of Ninh Binh CPP. Thus it is not economically feasible for Ninh Binh CPP to adopt biomass co-firing in the plant. The negative NPV for case 2 is due to the fact that the Levelized Cost of Electricity for biomass co-firing is higher than the electricity tariff at which the plant sells electricity, which is 5.4 UScent/kWh.

Greenhouse gases emission

Based on Equation 18, the GHG emission from biomass combustion at Mong Duong 1 CPP is 260,107 ton CO₂e per year (with the emission factor of rice straw combustion listed in Table 9) while the emission from biomass transportation is 2,281 ton CO₂e/year (with the emission factor for road transportation listed in Table 10). This results in 262,389 ton CO₂e/year of total GHG emission for

biomass co-firing. Currently, coal is still transported to Mong Duong 1 CPP by truck, however, a new 5km-long conveyor belt will be in operation in September to deliver coal from Khe Cham coal mine to the plant (Quang Ninh News 2015). Because the distance is small, therefore, the emission from conveyor belt transportation is assumed to be negligible. Thus, the total emission of from coal in Mong Duong 1 CPP is from coal combustion only. The coal type used in Mong Duong 1 CPP is 6a, based on Vietnamese coal standard (VINACOMIN Nui Beo 2015). With the heating value of 4645 kcal/kg, this coal type falls into the sub-bituminous category, then the emission factor from coal combustion is taken as 0.0966 kgCO₂e/ton of coal (see Table 9). Using Equation 18, the GHG emission from coal combustion in Mong Dong CPP is estimated at 292,848 ton CO₂e per year. This leads to the total emission reduction of 30,460 tonCO₂e/year from co-firing rice straw in the plant. The emission reduction is about 10.4% of current emission from the 5% capacity of the plant run by coal.

Applying Equation 18 and Equation 19 to calculate the GHG emission from rice straw with the emission factors for rice straw combustion and road transportation as in case 1, the emission from biomass combustion and transportation for Ninh Binh CPP are 53,568 and 104 ton CO₂e/year, respectively. Therefore, the total GHG emission from biomass co-firing in this case is 53,672 ton per year. Coal is transported from Cam Pha to Ninh Binh CPP by barges with 2000 ton of coal per shipping which results in 210 shipping/year. The transportation distance is about 200km by waterway. As the emission factor for barges transport is 0.31 kgCO₂e/ton-km (see Table 10), the emission from coal transportation is estimated at 306 ton per year using Equation 19. Emission from coal combustion is 60,311 ton CO₂e/year, and then the total annual emission from the plant with 100% coal is 60,617 ton CO₂e. Thus, the emission reduction from rice straw co-firing in Ninh Binh CPP is 6,945 ton CO₂e per year. This means the plant could cut off 11.5% of its current GHG emission (for the capacity substituted by co-firing) by applying co-firing technology.

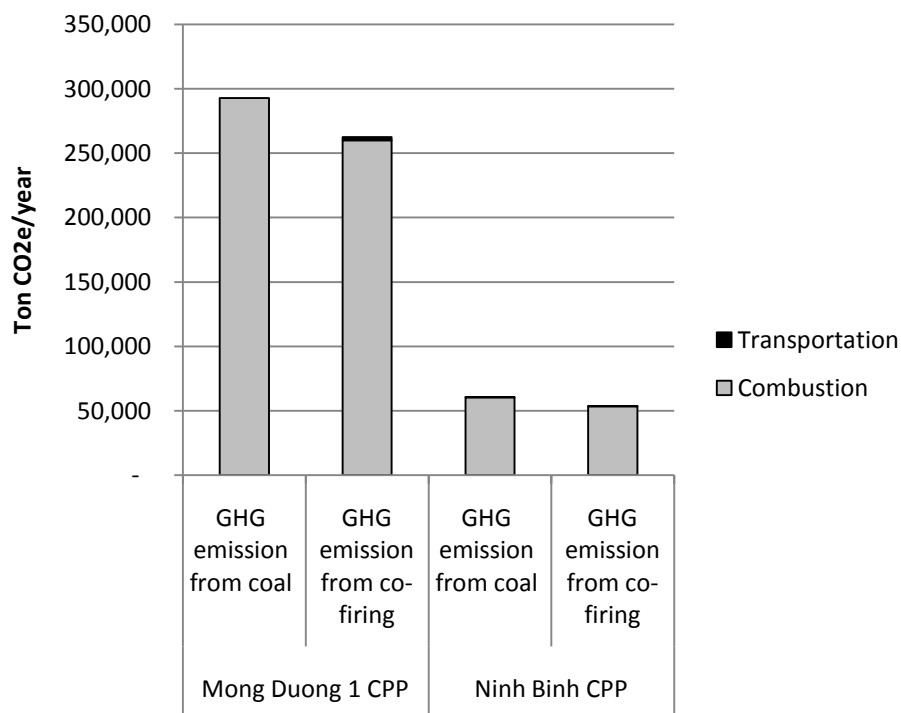


Figure 17. GHG emission from coal and biomass co-firing in two cases

Local air quality

Because the biomass feedstock selected in these two cases is rice straw, there could be additional effect from utilizing straw for co-firing to local air quality. Currently, the farmers mostly burn rice straw in the open air in the field right after harvesting, which cause serious air pollution in large area. In the field near the cities, the rate of open straw burning after harvest could reach 60-90% (M. D. Nguyen 2012). The air pollutant emission from in-field straw burning in Red River Delta covers a large area, including Hanoi, by a thick smoky coat (see Figure 18). The gases/pollutants emitted from open straw burning include CO₂, methane, carbon monoxide, NO_x, N₂O, SO_x and particulates.



Figure 18. Hanoi is covered by smoke (left) and straw burning in the field (right)

Co-firing could reduce the amount of open burned rice straw since the farmer would sell straw to the plant after harvesting rather than burning in-field. The air pollutant emission is then concentrated in the power plants, where there are equipments for air filtering before release to the atmosphere. Therefore, co-firing in the two plants could contribute to improve the local air quality, especially during the rice harvesting season in Red River Delta.

Extra income for farmers

The extra income for farmers depends on the rice straw yield of their field. Since the rice straw yield vary from place to place, it is assumed that the yield is taken for each province as listed in the Vietnam Statistical Yearbook 2013 published by General Statistical Office (GSO 2013). Because Mong Duong 1 CPP collects straw from 4 different provinces (Quang Ninh, Bac Giang, Hai Duong and Hai Phong) , the extra income for farmers is calculated for each province and the results are shown in Table 13. For the farmers in Ninh Binh province, their extra income if they sell rice straw to Ninh Binh CPP would be 212 USD per ha per year. To collect rice straw, however, the farmers need to invest in buying straw winder and labor time. The price for straw winders varies from 4,000 to 18,000 USD (Thanh Phong 2015). If the farmers invest on straw winders, they could rent it for about 37-47 USD per ha. Assuming that the farmers have to rent the winders at 40 USD/ha, the net extra income will be the gross income minus the winder rental cost (see Table 13). Compare to the average annual income of farmers in Vietnam at 3100 USD per ha per year (Hoa An 2015), these extra income can add to 4.6% - 6.3% of current income per ha of cultivation for farmers in the mentioned provinces.

Province	Extra income (USD/ha per year)	Net extra income (USD/ha per year)
Quang Ninh	183	143
Bac Giang	199	159
Hai Phong	234	194
Hai Duong	183	143
Ninh Binh	212	172

Table 13. Extra income for farmers in related provinces

Jobs created from biomass co-firing

As discussed in Chapter 4, the jobs created from bioenergy sector include direct, indirect and induced jobs. However, this study will focus on the calculation of direct jobs only. For these cases, direct jobs are jobs in biomass supply chain and operation and maintenance.

For rice straw collection, an assumption is made in which the straw is collected by straw winders. This winder require one driver with the operation capacity of 400-500 rolls/day (Hoang Thai and Giao Linh 2015). With the size of the roll is 15 kg then the capacity of the winder is 6.57 tons/day, given that the winder can collect 450 rolls/day. The amount of rice straw requires for generate 1 MWh of electricity in Mong Duong 1 CPP is about 0.8 ton. Assuming that the working hour per day of one straw winder is 8 hour, then the total hour per year required to collect the amount of biomass needed is calculated at 315,504 hours per year. Because 1 FTE jobs is defined as 30 working hours per week, which equivalence to 1560 hours per year, the number of FTE jobs for biomass collection is 202.

For straw transportation, jobs are created for drivers to deliver straw to the plant. In case of Mong Duong 1 CPP, the transportation distance is about 70km. Given the traffic condition in Vietnam, it is assumed that the travel time for one delivery from the collection point to the plant is 1.5 hour one way. Thus the round trip could take 3 hours for supplying 20 tons of rice straw to the plant (with truck load of 20 tons). Thus the total hour required to transport is 38,866 hour per year and the number of FTE jobs is 25.

The labor requirement for operation and maintenance of biomass co-firing process within the plant is taken at 0.12 hour/MWh (Singh and Fehrs 2001). Then the total working hour required for operation and maintenance per year is 39,000 hour which equivalence to 25 FTE jobs per year.

Apply similar calculation for Ninh Binh CPP with the total amount of rice straw needed is 53,362 ton per year, the working hour required to collect this amount of straw is 64,977 hours. The number of FTE jobs for biomass collection is then calculated at 42 FTE jobs. For transportation, the travel distance is only 16 km thus the time for making a round trip delivery of 20 ton straw is estimated at

0.7 hour. The number of FTE jobs per year for biomass transportation is 1.2. With the same labor requirement at 0.12 hour/MWh, the total working hour for operation and maintenance is 4,500 hours per year.

Table 14 summarizes the of number of direct FTE job created from co-firing in two plants, and Figure 19 illustrates the breakdown of direct job created.

Activity	Mong Duong 1 CPP	Ninh Binh CPP
	FTE jobs/year	FTE jobs/year
Biomass collection	203	42
Biomass transportation	25	1
Operation and Maintenance	25	3
Total	<u>253</u>	<u>46</u>

Table 14. Summary of labor requirement for co-firing in the two plants

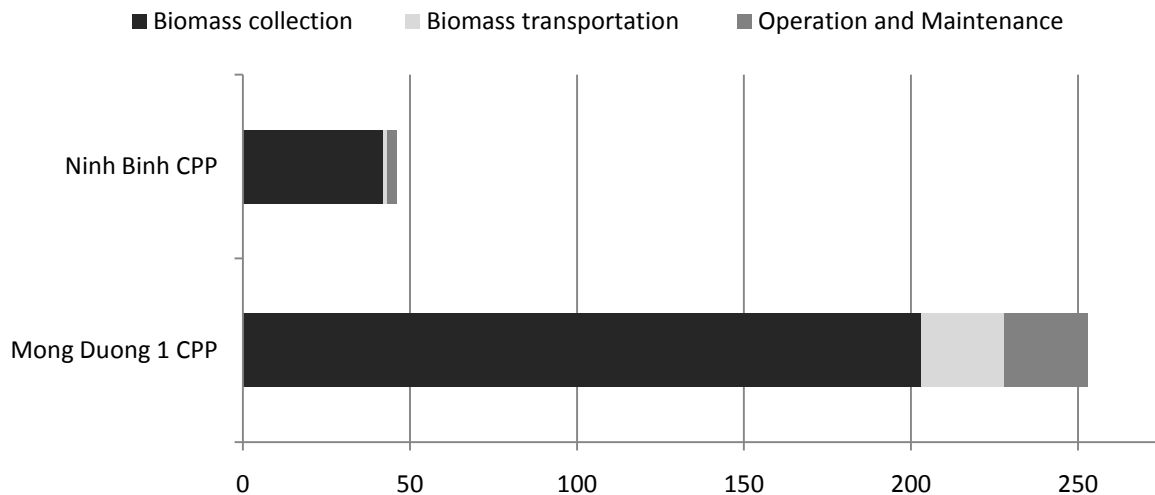


Figure 19. Breakdown of direct job created

Effect on national trade balance

The reduction of coal consumption from co-firing could have effect on national trade balance. This could reduce the coal import amount or increase the amount of coal export, depend on how the amount of coal saved is used.

As mentioned in the introduction, with the increase of coal share in total power generation, Vietnam will have to rely on import to supply coal for coal power plants. Thus, if the coal conserved is used domestically, then there will be about 181 thousand tons of coal could be avoided from importing.

The amount of coal saved from biomass co-firing could help to increase the coal export and thus earn more money from the difference between coal export price and coal price sell to power plant. The coal price for power generation and for export for case 1 and 2 is referred to Table 11, with coal type for case 1 is 6b and 4b for case 2. Hence, the extra revenue from coal export is estimated at 1.4 million USD per year for Mong Duong 1 CPP case and about 345,000 USD per year for the case of Ninh Binh CPP based on Equation 22.

5.3. Discussion

Table 15 provides the summary of results of indicator calculation for Mong Duong 1 CPP and Ninh Binh CPP. For both cases, the preliminary assessment of feasibility shows that it is technically feasible to co-fire in the two plants in term of biomass feedstock supply. The two plants are located in Red River Delta where rice is the major agricultural crop, thus the rice straw produce in the area is adequate for co-firing. In case of Ninh Binh CPP, since the capacity of the plant is small, the amount of biomass required can be supplied within the province. Mong Duong 1 CPP is ten times larger than Ninh Binh CPP in capacity; however, the biomass required is only 5 times higher because the plant efficiency is higher. Although rice production of Quang Ninh province could not provide enough rice straw for co-firing in Mong Duong 1 CPP, the plant can still collect the biomass feedstock from the provinces nearby within the distance of 71 km from the plant. In the case of Mong Duong 1 CPP, rice straw transportation by boats, barges or by train could also be considered. Since the plant need large quantity of biomass, delivery by these modes of transportation could offer more load per shipping. This will require a collection network to gather rice straw at the dock or train station.

Assessment of economic indicators for the investment in rice straw co-firing of Mong Duong 1 CPP shows that it could still be profitable as demonstrated by a positive NPV. The positive result from NPV is obtained with the LCOE of 4.5 UScent/kWh which is lower than the electricity selling tariff. However, the plant will have to spend an extra amount of 2.5 million USD per year to purchase rice straw for co-firing. This is due to the fact that the coal price for the plant is relatively low with subsidies from the government for coal price for electricity generation. In addition, the plant need to collect rice straw from other provinces, which increase the biomass transportation price. Currently, there is no subsidy for biomass feedstock for power generation yet. Despite of positive NPV, the extra expense for rice straw purchase makes biomass co-firing in Mong Duong 1 CPP not economically attractive from the view of investor because with the same revenue from electricity sales, the plant have to spend 2.5 million USD/year more in buying fuel. However, if the coal price for power generation increases in the future and if there is supporting mechanism in biomass price in power sector, fuel cost saving could turn into positive. The calculation shows that when the coal price increase from current rate of 52.69 to 68.62 USD per ton then the fuel cost saving is zero. If the coal price gets higher than that number, the plan will have economic benefits from coal substitution by biomass.

For Ninh Binh CPP, the economic evaluation indicates that it is not profitable for the plant to employ biomass co-firing since the NPV get negative value. This negative NPV is the result of LCOE of 6.6 UScent/kWh, which is higher than the electricity selling tariff. The high LCOE is due to the high rice straw cost and the low efficiency of the plant. Ninh Binh CPP has the overall efficiency of only 21.77%, which is the lowest among all coal power plants in Vietnam while the average efficiency for coal power plants in Vietnam is 32%. Low efficiency leads to higher biomass required to generate 1 kWh of electricity, thus increase the cost of electricity generation.

Dimension of indicator	Indicator	Value		Unit
		Mong Duong 1 CPP	Ninh Binh CPP	
Technical aspect	Overall efficiency with co-firing	38.59	21.62	%
	Efficiency loss	0.25	0.15	%
	Biomass needed	259,107	53,362	ton/year
	Biomass available density	52.79	68.67	ton/km ² -year
	Collection radius	71	16	km
	Number of Truck/day	35	7	
Economical aspect	Biomass unit cost	41.31	38.15	USD/ton
	Levelized cost of electricity	4.5	6.6	UScent/kWh
	Net Present Value	1.85	- 6.45	Million USD
	Fuel cost saved	-2,485,162	31,533	USD/year
	Extra revenue for coal export	1,403,882	345,302	USD/year
Environmental aspect	GHG emission reduction	30,460	6,945	ton CO ₂ e/year
	% emission reduced	10.4	11.5	%
	Resource conservation	155,987	24,664	ton coal/year
Social aspect	Extra income for farmer	143 - 194	172	USD/ha
	Number of direct job created per year	253	46	FTE jobs/ year

Table 15. Result of indicators calculation for 5% rice straw co-firing in the two power plants

The assessment shows that the investment in biomass co-firing in the two cases is not yet attracting in term of economic, however, if the government has some supportive mechanisms for development of bioenergy that include incentives and subsidies for biomass co-firing then the investment could be economically profitable for the investors.

In principle, biomass co-firing offers a way to mitigate GHG emission since biomass is considered as a “carbon neutral” fuel. Both cases show that GHG emission could be reduced by co-firing rice straw with coal with the amount of 30,460 and 6,945 tonCO₂e per year for Mong Duong 1 CPP and Ninh Binh CPP, respectively. This equivalence to 10.4% and 11.5% of emission reduction, compared to current level of emission of the part that replaced by co-firing in the two plants. Since the Clean Development Mechanism under Kyoto Protocol ended in 2012 and the carbon credit price at present is very low, the economical benefit from selling carbon credits for the plants is not viable. However, in the future there will be more mechanism that support carbon credits trading and thus create benefits from GHG emission reduction. For example, Vietnam government has signed the bilateral agreement with Japanese government to trade carbon credits to Japan within the Joint Crediting Mechanism (JCM). This could be the possibility to make profits from selling carbon credits for the plants. For example, in case of Mong Duong 1 CPP, the Net Present Value could increase from 1.8 million USD to 3.2 million USD if the carbon credit price is at 5 USD/ton CO₂e.

In terms of social well-being, the indicators also demonstrate positive results. Straw co-firing with coal in the two plants can increase the annual income for farmers by 6-8% from selling rice straw. For VINACOMIN, the extra revenue from coal export is 1.4 million USD per year for the first case and 345,000 USD/year for the second one. This number varies with the coal price for export and coal price for electricity generation. When the difference between the two prices increases, the extra revenue for VINACOMIN also increases and vice versa. Biomass co-firing also offers job opportunities throughout the project lifetime, in which, most jobs are created from biomass collection because the way of gathering biomass in Vietnam is still in small scale. If the biomass harvesting/collecting process is more industrialized then the number of working hours for this part will be reduced as well as the cost.

6. Conclusion

National energy security, climate change as well as environmental concerns are the major factors that drive attention to bioenergy, especially in electricity generation from biomass. In the context of Vietnam, co-firing biomass with coal in coal power plants is one of the options for utilizing biomass for power generation, which offers several advantages. This study examines the feasibility and sustainability of co-firing agricultural residues with coal to produce electricity since these residues are abundant and its total potential is not yet utilized for power generation purposes.

A set of indicators is built to evaluate the feasibility and sustainability of co-firing biomass with coal in Vietnam in term of technical, economical, environmental and social dimensions. These indicators are applied into two real cases in Vietnam: Mong Duong 1 Coal Power Plant and Ninh Binh Coal Power Plant. The results in feasibility assessment show that biomass co-firing at the rate of 5% is possible in term of technical aspect in both plants. For Mong Duong 1 CPP, the biomass supply is adequate in the area within the collection radius of 70km. In case of Ninh Binh CPP, the straw collection radius is 16km. However, the economical profits from co-firing for the two plants are not viable yet. The key factors to make biomass co-firing economically feasible in Vietnam are electricity selling tariff and biomass cost. Carbon credits from emission reduction could also be a potential factor that positively impacts the profitability of biomass co-firing in the future.

Although biomass co-firing in Vietnam is not yet feasible in term of economic, it still offers various environmental and social benefits. Both cases demonstrate that co-firing could significantly reduce greenhouse gases emission compare to the current emission of the plants with the percentage of GHG emission reduction of 10.4% for the first case and 11.5% for the second one. For the case study, co-firing shows the potential to mitigate the air pollution from open straw burning in the field after harvesting season. Biomass co-firing can also bring economic benefits to other entities such as farmers and VINACOMIN. The case studies show that by selling rice straw to the plants for co-firing, farmers could increase their annual income per hectare of paddy field by 4.6 - 6.3%. Biomass co-firing creates numbers of direct jobs for biomass collection, transportation and operation and maintenance. For the case of Mong Duong 1 CPP, co-firing could provide 253 FTE jobs per year in total and this number is 46 for the case of Ninh Binh CPP.

The feasibility and sustainability evaluation indicates that co-firing biomass with coal is still a promising option to be considered among various technologies for utilizing biomass in energy production. Biomass co-firing could offer a way to increase the share of biomass in power generation as well as to reduce greenhouse gas emission. In the National Power Development Plan VII, the road map for the development of electricity generation from biomass is to install 500 MW in 2020 and to 2000 MW in 2030, thus increase the proportion of biomass in power generation to 0.6% in 2020 and 1.1% in 2030. The national target is to cut down GHG emission in energy sector by 8-10% compare to 2010 level by 2020. The results of the case studies demonstrate that biomass co-firing can contribute to achieve those goals. For example, 5% co-firing in 1080 MW Mong Duong 1 CPP is equivalence to 54 MW installed capacity of electricity generation from biomass and reduce the current GHG emission of the plant by 10%.

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