Socio-economic impacts of co-firing in Vietnam: The case of Ninh Binh Coal Power Plant

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Abstract

Co-firing biomass with coal is a relatively low-cost technology to utilize biomass for electricity production compared to dedicated biomass power plant. Co-firing could help to reduce the negative impact of coal power plants to economy, environment and society. Vietnam has potential to develop co-firing base on the abundant of biomass resources and because Vietnam will continue to build more coal-fired power plant in the next 2 decades as stated in the latest National Power Development Plan.

Among the co-firing technologies, direct co-firing is the most suitable for Vietnam context. Despite of low biomass ratio, direct co-firing offers low investment cost and could utilize most of the biomass feedstock. Vietnam has huge biomass potential, especially the agriculture and forestry residues. These biomasses should be considered first as feedstock for co-firing. Biomass pellets is also a good choice in term of technical features and local supply. However, the price of pellets is not yet competitive with coal or agricultural residues.

Economic benefit of co-firing would be higher in the plants that has following features: assess to stable biomass supply, biomass price competitive with coal, incentives and support in term of market for renewable energy utilization and waste reduction. Vietnam should start experimenting co-firing in the coal power plants that located in the area where biomass resource is available, easy to collect and deliver to the plant, using imported coal such as Vinh Tan 2, Duyen Hai 1, Long Phuoc 1…; or the plants that are soon or already depreciated such as Ninh Binh, Uong Bi or Pha Lai to utilize the existing infrastructures.

The case study of co-firing 5% rice straw with coal in Ninh Binh Coal Power Plant shows that co-firing could bring benefit to the plant owner in the condition that lack supporting mechanism for co-firing as well as with the absent of carbon credit. Farmers and workers that work in biomass supply chain also benefit from co-firing, especially farmers. In addition, co-firing provide significant positive externalities, in which the most notable is health benefit from reducing air-borne pollutants. Greenhouse gas emissions reduction adds a small part to the overall benefit of co-firing.

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1. Why considering co-firing biomass with coal in Vietnam

According to the latest National Power Development Plan, Vietnam will continue developing coal as the main energy source for electricity production. Coal will have the share of 53.2% total power generation by 2030. With the increasing number of coal power plants, Vietnam will have to face many environmental and socio-economic challenges from coal import for power generation to emissions pollutants that cause health problems.

In this context, co-firing biomass with coal offers a way to utilize the domestic biomass resources with much lower cost than building new-dedicated biomass power plants. Co-firing can reduce the use of coal (a depleting fossil fuel with increasing price) in the coal power plants and the emission of greenhouse gases as well as other pollutants that are harmful to environment and human health.

In addition, another condition that favor co-firing in Vietnam is the rich biomass resources in the country. Vietnam has tropical climate, which facilitate the growth of crops and plants. With the big share of economics is agriculture and large area of forest, biomass resources in Vietnam is renewed regularly.

1.1. Technical advantages

Co-firing has been studied and applied in many countries. According to the report of IRENA 2013, about 230 plants use co-firing technology by 2012. These plants are mostly located in Europe and North America with the capacity ranging from 50 MWe to 700 MWe. A recent studied shown that there are 46 countries that applied this technology such as United Kingdom (16 projects), Germany (15 projects), Denmark (5 projects), Finland (14 projects), Belgium (5 project), Austria (5 projects). Co-firing technology is mostly used in plants with pulverized boilers or fluidized bed boilers.

Apart from 100% dedicated biomass power plant technology, co-firing does not require continuous biomass supply. Power plant can still be in operation with coal when there is not enough biomass. This technology allows using different type of biomass, based on the same production line.

Co-firing can utilize biomass to produce electricity at higher efficiency compared to dedicated biomass power plant. Studies shown that efficiency of co-firing could be 30 – 38%, much higher than efficiency of direct biomass combustion in dedicated biomass power plant. Moreover, the power consumed to operate boilers does not change compared to the case of coal fired only but a part of fossil fuel (coal) is replaced by renewable energy source (biomass).

1.2. Economic benefits

The conversion of coal-fired power plant to co-firing can use the existing system of the plant, thus lower the investment cost and the installation time is shorter.

With the development of coal power plants as planned, the demand for coal will increase in great quantity. The country will have to import coal for electricity generation starting from 2017. By 2020, the demand for imported coal will be 20 million ton. Coal import will cause an outflow of foreign currency out of the countries, which led to the negative impact to national trade balance. As a consequence of coal scarcity, the price of coal should increase over time. This will affect the national trade balance since Vietnam has to pay foreign currency to purchase coal from other countries. With co-firing, there will be an amount of coal consumption reduced per year. This amount of coal saved could be used domestically, hence lower the amount of coal import. Replacing coal with the local produced biomass will help to cutting the dependence on imported resource while ensuring the national energy security.

1.3. Environmental benefit

One of the advantages of co-firing biomass with coal is to lower the carbon emission. This is because biomass has lower CO_2 emission factor than coal. Biomass is considered as "CO_2 neutral". This can be explained by the fact that CO_2 is fixed by plants. The amount of CO_2 released from biomass combustion is equal to the amount of CO_2 absorbed. However, the "CO_2 neutral" feature cannot be extended to the whole life cycle of biomass. Emission reduction also depends on how biomass is produced, processed, transported, used and stored…In addition, co-firing could reduce CH_4 emission and other greenhouse gases/ Compared to 100% coal combustion, co-firing biomass with coal significantly reduces NO_x and SO_x emission, two gases that also cause greenhouse effect and ozone depletion. This is because biomass content less N and S than coal.

Moreover, if agricultural residue is used for co-firing, it will help to address the waste issue. For example, most of the straw is burn right in the field after harvesting, which cause air pollution. Using straw for co-firing will cut down that harmful activity and reduce the negative environmental impact of open field burning of rice straw.

1.4. Social benefits

Development of co-firing biomass with coal will encourage the production of biomass, which provide benefit to the society in many ways: improve farmers' income, create biomass market and give value to the agricultural "wastes" such as bagasse, rice husk, rice straw…Co-firing create biomass supply chains which include biomass collection, biomass process, transportation. This will create jobs in each steps of the supply chain.

With the positive impact to environment as mentioned is section 1.3, co-firing could contribute to mitigate the negative impact of co-firing to human health. This will be described in more details in the case study.

1.5. Barriers to apply co-firing technology

There are barriers to the adoption of co-firing. These include technical and non-technical barriers. The first technical should be mentioned is the unstable of biomass supply or the competition with other sectors that also use biomass. For example, straw can also be used as cattle feedstock; soybean, peanut, coconut can be used to produce bio-diesel beside of using as food; wood chip and saw dust can be used for paper industry.

Biomass has lower carbon content, higher oxygen content and lower heating value compared to coal. This means it require more biomass in weight to produce the same amount of heat from coal. In addition, high moisture content makes biomass easier to be degraded during transportation and storage, which affect greatly the combustion quality.

When the plant use pulverized coal boiler, the difficulty for co-firing is to grind biomass into desired size to optimize the co-combustion process. Analysis shown that normal size of coal powder is about 100 µm, while the average size of biomass particles is 3 mm, and for some biomass it could be 25 – 30 mm. The density of coal is about 881 kg/m^3, 10 times denser than that of biomass (about 80 kg/m^3). Some studies indicate that when mixing biomass with coal at the rate of 5%, this equivalent to 1 m^3 biomass mix with 1.7 m^3 coal. Low density of biomass make it more difficult and costly for transportation and storage.

The content of inorganic substances in biomass is more diverse compared to coal. That leads to the problem of slagging, fouling and corrosion of the equipment, thus shorten the lifetime of equipment, and increase the cost for maintenance.

Non-technical barriers for co-firing include the coal subsidy from the government to keep low electricity price for the electrification target, which make biomass less competitive to coal. Low electricity tariff is preventing the development of bioenergy and other renewable energy sources. Lack of specific policies for co-firing is also a barrier. Moreover, the word "coal" appeared in co-firing technology also make it difficult to reach the financial support from foreign donors such as World Bank or ADB. Although co-firing technology involves the substitution of coal used in coal power plant by a renewable resource, but with its policy that not encourage coal development, World Bank has implied that the organization will not financing any project related to coal including co-firing.

2. Factors that impact the adoption of co-firing

Co-firing technology exists in many countries. However, co-firing solutions might vary due to the specific conditions in each country. As mentioned in section 1, co-firing technologies can use different type of biomass and can be done in plants that use different coal boiler technologies. To adopt this technology, it is important to select the suitable solution (including type of biomass feedstock, co-firing technology, etc.). This is to ensure not only the economic benefit but also the sustainable development criteria.

2.1. Biomass feedstock for co-firing

The choice of biomass type to be co-fired depends on several factors such as co-firing technology, resource supply, price and sustainability criteria. Technically, all biomass type could be co-fired in coal power plant. There are demonstrations and tests worldwide on co-firing of different type of biomass such as biomass pellets, wood chip, agricultural and forestry residue, municipal solid waste and even liquid waste. However, each of the co-firing technology has different characteristics and ability to co-firing different type of biomass feedstock. For example, indirect co-firing and parallel co-firing can co-firing most biomass because in these technologies, biomass is converted in separate system with coal. On the other hand, direct co-firing is more selective on the biomass feedstock in term of fuel characteristics (moisture content, grindability…).

Since Vietnam has great biomass potential, especially on agricultural residues, this type of biomass should be considered first for co-firing. In many places, agricultural residue such as rice husk and rice straw is not yet utilized and mostly become waste. Co-firing is away to use these "wastes" to produce energy, thus give value and create the market for these residues. Moreover, utilization of these biomasses could contribute to address environmental issues such as the open burning of rice straw in the field after harvesting. In-field burning of rice straw is causing serious air pollution in the Red River Delta, including Hanoi, every harvesting season. It is estimated that 60 to 90% of straw is burned in the open air (Nguyen 2012). When straw is co-fired in the plant, the amount of straw burned remains the same but it is more concentrated and filtered by the air pollutant control system in the plant. Thus, the pollution from in-field burning of rice straw could be mitigated. However, using agricultural residues has some challenges such as the supply price varied depends on season and market demand, collection of this scattered resourced, transportation and storage.

Biomass pellets is also the choice of many plants that do co-firing. Pellets has higher heating value and density and lower moisture content compared to the raw biomass, thus it is easier to transport and storage. Grindability is also another advantage of pellets over raw biomass. Vietnam is one of the pellet exporting countries with the biggest market in Korea and Japan. Co-firing could help open the domestic market for pellets and local consumption of local products is sustainably better. The major barrier for co-fired pellet is price. The price of pellets produced in Vietnam imported to Korea early 2016 is about 98 USD/ton. Although the price for domestic buyers would be lower, this price still not be able to compete with coal.

Torrefied biomass is the biomass that has been through heat treatment to obtain better fuel properties for combustion or gasification. Torrefied biomass is gaining a lot attention as secondary fuel to be co-fired with coal since its combustion characteristic is quite similar to coal. However, the cost for torrefaction is still high and the supply is quite limited.

To ensure the sustainability of biomass production and utilization as mentioned in the guideline of FAO or GBEP, sustainable criteria should be considered when selecting the biomass feedstock for co-firing. Dedicated energy crops must be assessed on their sustainability such as water use, land use, life cycle assessment of greenhouse gas emission and so on make sure the development and usage of these crops satisfy the sustainable criteria.

2.2. Technical factors

Which plants in Vietnam should do co-firing

In Vietnam, coal power plants use either of the two boiler technologies: Pulverized Coal (PC) boiler and Circulating Fluidized Bed (CFB) boiler. Technically, co-firing could be done in all Vietnamese coal power plants since it was successfully applied for both boiler types. CFB boilers can co-fire higher biomass percentage than PC boiler. The cost to retrofit CFB boiler to adapt to co-firing is lower than that for PC boiler. This cost is about 50 USD/kW for CFB boilers and 100 USD/kW for PC boilers. 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, which is 500 000 USD.

However, if we consider the economical aspect, there are factors that make some coal power plants more suitable for co-firing than the others, mostly due to the competitiveness of biomass with coal. Plant location, coal type, plant capacity, lifetime and environmental impact of the plants are some of the factors that influence the choice of coal power plant to be converted to co-fire. Plants located far away from coal mines and in the area that biomass resources is abundant or plants using low rank imported coal should be considered for co-firing prior to plants that close to the coal mine and using domestic coal, not easy to supply biomass. Small plants, already or almost reach the end of their lifetime are suitable for co-firing demonstration because they require less investment cost, less impact to the grid, easy to fulfil biomass demand for co-firing. Some Vietnamese coal power plants that should be first considered for co-firing are Ninh Binh, Uong Bi, Pha Lai (belong to the small, old plant category) and Vinh Tan, Duyen Hai, Long Phu (located in the rich biomass region, using imported coal).

Co-firing technologies

There are different co-firing technologies as described in Figure 1 : direct co-firing, indirect co-firing and parallel co-firing. All these technologies has been done in coal-fired power plants in other countries. Of which, direct co-firing is the most used one due to low installation cost, utilization of existing infrastructure, simple to retrofit the plant for co-firing (Table 1). This technology is also the most suitable choice for Vietnam's approach to co-firing.

Blending biomass with coal before grinding (Figure 1 a) is the simplest and cheapest direct co-firing option. However, the co-firing ratio as well as the biomass type could be co-fired by this method is quite limited. The fibrous biomass is not easy to be ground with coal and could affect the operation of coal grinding and injecting system. But if the co-firing ratio is below 3 – 5% then the impact of biomass and coal mixture to the complete coal-fired system is not so significant and do not require major changes.

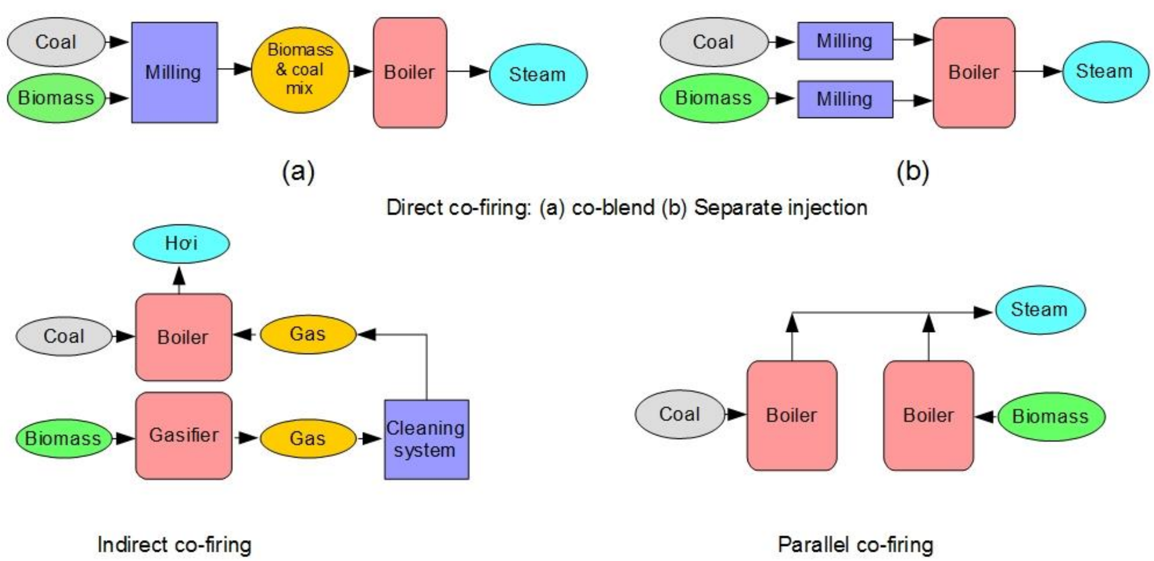

Figure 1. Simplified diagram of different type of co-firing technologies

Direct co-firing with separate biomass processing line and injection (Figure 1 b) will not affect the coal grinding and spraying system. However, it requires the installation of new grinding and injecting system for biomass thus increase the investment cost. This technology allows higher percentage of biomass to be co-fired (up to 15%).

The weaknesses of direct co-firing, however, are the limited co-firing rate due to technical features such as corrosion from slagging and fouling. In addition, coal ash and biomass ash is mixed in co-firing, thus it needs to be examine the different between coal ash and mixed ash before using mixed ash for making construction materials.

Table 1. Description of different co-firing technologies

	Direct		**Indirect**	**Parallel**
Description	Mix and grind coal with biomass before injection to furnace	Grind biomass separately then injected to furnace with separate injector	Separate gasification unit	Mix and grind coal with biomass before injection to furnace
Co-firing ratio	Low (<5% in PC boiler and up to 20% in cyclone boiler)	Higher	Not limited	Not limited
Ash	Mixed biomass and coal ashes	Mixed biomass and coal ashes	Separate biomass and coal ashes	Separate biomass and coal ashes
Cost	50-500 \$/kW[1,2]	760 – 900\$/kW[1]	3000-4000\$/kW[1]	

1(Baxter 2005), 2(IRENA 2013)

Co-firing technologies are now commercialized with many consulting companies that had experiences in this field such as Ecofys (UK), Alstom (France), Dong Energy (Denmark), Doosan (Korea)…An example of coal power plant that successfully converted to co-firing is Drax Power Station (UK). This is the biggest power plant with the capacity of 4000 MW. The plant is using direct co-firing with the biomass (mostly wood chip and pellet) supplied from domestic and abroad. Initially the co-firing ratio is 10%, which equivalent to 400 MW capacity operating on biomass. Currently, 2 units of the plant is completely converted to 100% biomass.

2.3. Economic factors

Biomass supply

Fuel is the most important input of a thermal power plant; therefore, it is necessary to ensure the biomass supply for co-firing throughout the lifetime of co-firing project. This could be done with a long-term biomass supply contract. Determining the biomass supply area, negotiating price and having long-term contract are extremely important, not only for the plant but also for the suppliers, especially when agricultural residue is selected for co-firing because this type of biomass is scattered and depends on season.

Ensuring the biomass supply could be easier if biomass pellet is considered for co-firing because Vietnam already has pellet producing system for export. The biomass pellet production of Vietnam is about 2.4 to 3.6 million ton/year (2014) with more than 300 plants, of which 70% are in the South and the rest are in the North. However, after 2015 the development of pellets production in Vietnam has slowed down due to the decrease of pellet price in Korea market (the main market of Vietnamese pellets). This could be an opportunity for co-firing to emerge in Vietnam in order to utilized the pellets production system and create domestic market for pellets.

Revenue

The majority part of plant's revenue is from selling electricity. Avoided cost tariff is established for biomass power project but not yet mentioned co-firing as biomass power project. Therefore, it is not clear whether power generated from co-firing could apply this tariff. While waiting for specified policy for co-firing, power plants could negotiate the price for electricity created from co-firing with the power purchase companies. In addition, the plants could also seek for other sources of revenue such as carbon credits or selling ashes to make construction materials. Vietnam is now taking its first steps to create domestic carbon market. When there is carbon market, it will be an opportunity for projects in reducing greenhouse gas emission including co-firing project to increase the economic benefit.

2.4. Co-firing policy

In some countries, there are clean energy policies that force coal power plant to implement project to reduce their impacts. For example, Korean Government had established regulation that require power plants with capacity higher than 500 MW to produce part of their electricity from renewable energy. This policy has encouraged the coal power plants to convert to co-firing and created big market for imported pellets, including pellets from Vietnam. Co-firing is also mentioned in the latest National Power Development Plan of Vietnam. However, the more detailed regulations such as the roadmap for implementation of co-firing in Vietnam or supporting mechanism for this technology. These policies is very important for the adoption of a new technology not yet exist in a country.

The supporting mechanisms and incentives is necessary for co-firing to be economical feasible, even for the co-firing projects in developed countries in Europe or North America. These policies could be tax and capital incentives, feed-in tariff and carbon tax or carbon price. In Vietnam, there are just supporting mechanism for dedicated biomass power plants only as stated in Circular 44/2015/TT-BCT issued by Ministry of Industry and Trade in December 2015. These include that the power purchase company has to buy all the electricity produced and the power purchase agreement is signed for 20 years. Imported taxes is exempted for goods to create fix asset for biomass power project and income tax is discounted. However, these incentives are not yet be able to make biomass power or co-firing economically attractive to investors.

Electricity tariff is the key factor to the economic viability of a power project. For biomass-dedicated power plants, avoided cost tariff is applied. Avoided cost tariff is calculated and published annually by Ministry of Industry and Trade. The tariff for year 2016 is 7.35 – 7.55 UScent/kWh. The avoided cost tariff has included avoided cost for electricity and avoided cost for power generation. Although avoided carbon tax cost and avoided social cost were mentioned, they are not yet calculated and included in the avoided cost tariff because there is no regulation on calculation of these costs yet. According to our estimation for the case of Ninh Binh as presented in part 3 of this report, the avoided social cost is significant. If this cost is included in the avoided cost tariff, it will be substantial incentives for co-firing to be economical profitable for the plants that apply the technology.

3. Cost-benefit analysis for co-firing: the case of Ninh Binh power plant

Ninh Binh is the very first coal power plant of Vietnam. Its first unit was commissioned in 1974. The plant uses pulverized coal technology and includes 4 units, 25 MW each. Ninh Binh was selected to be the case study for cost-benefit analysis of co-firing because of the following reasons:

- The plant is old and at the end of its lifetime, thus it is easier to set up the demonstration of co-firing in this plant to utilize the existing infrastructure. In fact, Ninh Binh was chosen for the testing of co-firing the mixture between Vietnamese coal with the low rank Indonesia coal.
- The plant is small which it good for demonstration of co-firing at small scale. It is easier to supply biomass for small scale application and the demonstration will not have much impact to the grid.

- The plant is located in the Red River Delta where agriculture is developed and the biomass resources are abundant.
- The plant uses anthracite coal type 4a and 5b, which has higher quality and price than the coal type use in the new CFB coal power plants.
- The plant is located quite far from the coal mines with the coal transportation distance of 200 km.

Co-firing technology selected for the plant is direct co-firing. This is the most applied co-firing technology because it is simpler to implement and has lower investment cost compared to other technologies. The selected biomass feedstock is rice straw because in Red River Delta, straw is mostly burn in the open field, which cause severe air pollution for Hanoi and other provinces during harvesting season. Co-firing rice straw is not only giving value to rice straw but also reducing the harmful in-field burning activity. The ratio of straw co-fired with coal is set at 5% in term of heat. Low co-firing ratio does not require many changes or upgrade of the existing system, which help to reduce costs.

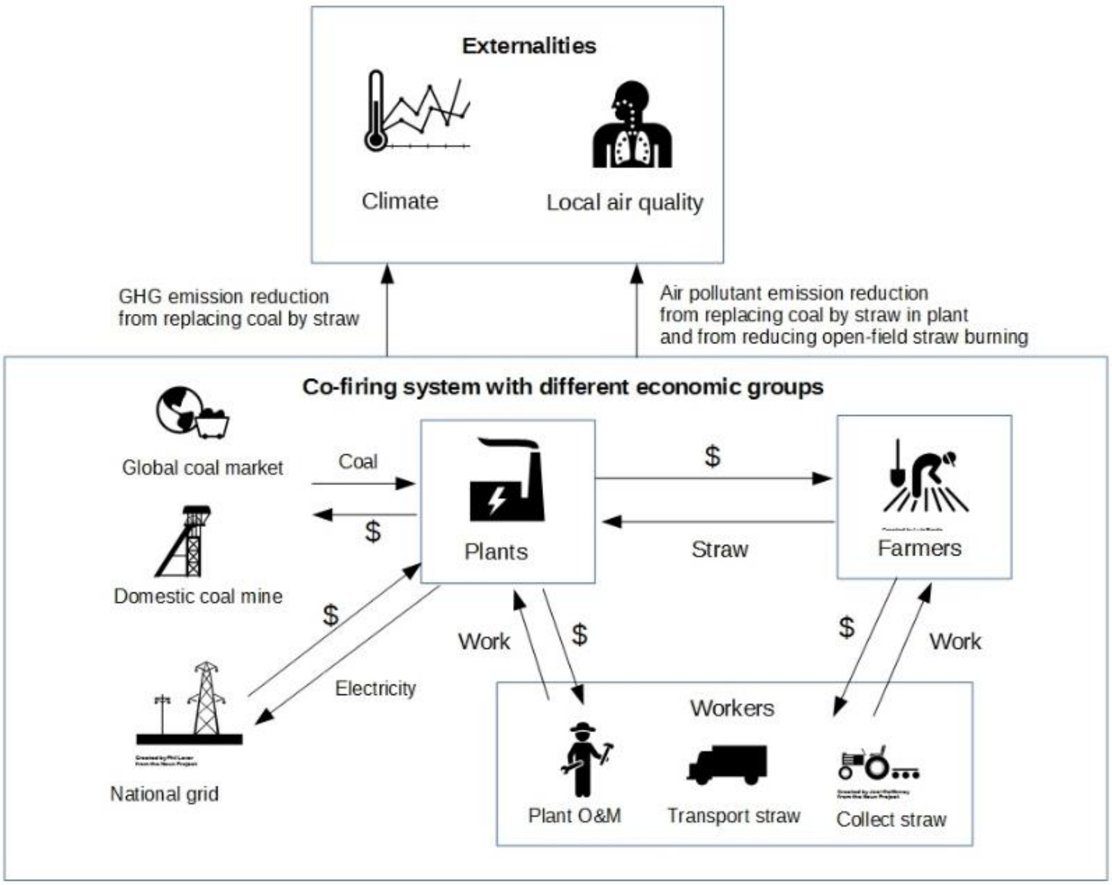

Figure 2. Description of the studied system

This study attempt to include most socio-economic impacts associated with co-firing by defining the system illustrated in Figure 2. The co-firing system consists of three different economic groups that directly affected by co-firing. We estimate the impact of co-firing straw with coal to these groups. Internal costs and benefits are defined as those occurring to the power plant owner. Co-firing could help farmer to increase their income by creating a straw market, which give value for this agricultural residue. Co-firing also create jobs through straw supply chain and the operation and maintenance of co-firing system in the plants.

Externalities of co-firing are those occurring to the global, local and national community. Positive externalities include benefit from greenhouse gas emission reduction, health benefit from air pollutants reduction due to co-firing.

The impact to soil quality as straw is removed from the field because of co-firing and the impact of reducing open burning of straw to local air quality are not yet included is the system. Data on soil quality, fertilizer used for rice crops, satellite images for air quality and in-field burning would be required for further research on these. Impact of co-firing to jobs in coal mining industry is not yet explored in this study.

3.1. Internal costs and benefits for the plant

Profitability

Net Present Value (NPV) is used in this study to evaluate the profitability of biomass co-firing during the analysis period of 20 years with the discount rate of 8.78%. NPV is calculated for 2 cases: baseline case (when the plant use 100% coal) and co-firing case (when the plant co-firing 5% straw). Opportunity cost is then defined as the difference between NPV of base case and of co-firing case.

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. The cash outflows include investment cost, fuel cost, operation and maintenance (O&M) cost and income tax. Inputs for NPV calculation are listed in Table 2.

Table 2. Input parameters for NPV calculation

Input parameters	*Baseline case*	*Co-firing case*
Capital cost[1]	*0*	*100 $/kW*
Coal consumption	*420 000 ton/y*	*391 025 ton/year*
Straw required	*0*	*53 362 ton/year*
Coal price	*81.98 $/ton*	*81.98 $/ton*
Straw price		*38.15 $/ton*
Fixed O&M cost[2]	*29.3 $/kW·year*	*32.24 $/kW·year*
Variable O&M cost[2]	*0.48 UScent/kWh*	*0.6 UScent/kWh*
Electricity tariff	*7.48 UScent/kWh*	
Discount rate	*8.78 %*	
Income tax rate	*25 %*	
Analysis period	*20 year*	

1(Hayter and Tanner 2004), 2(Broadman et al. 2013)

Calculated results (Table 3) show that the opportunity cost of co-firing option for Ninh Binh coal power plant is 1.5 million USD. This means the profit during 20 year of co-firing in the plant is higher than the profit of baseline case. The results indicate that in the conditions of this study, co-firing straw is economically feasible for the plant.

Table 3. Result on NPV calculation of both cases

NPV baseline case	NPV co-firing	Opportunity cost
105 254 k$	106 762 k$	1 508 k$

In this calculation, we not yet taken to account the revenue from carbon credit or selling coal ash because they are not yet realized in the plant. However, when the carbon market is created in Vietnam then it will contribute to increase the economic profit of co-firing to the plant.

Levelized cost of electricity (LCOE)

The Levelized Cost of Electricity (LCOE) is a measure of the overall competitiveness of different generating technologies. In this study, LCOE is calculated as the net present value of all costs over analysis period discounted at discount rate divided by total electricity generation. These costs include investment cost, fuel cost, O&M cost and tax. Investment cost is the cost to retrofit the plant for co-firing. It does not include the initial investment for the coal power plant.

Calculation of the LCOE for both cases (Table 4) shows that LCOE in co-firing case is smaller than that of baseline case. This means 1 kWh of electricity generated from co-firing is 0.03 UScent cheaper than 1 kWh of electricity generated from coal only.

Table 4. Results of LCOE calculation over analysis period of 20 year discounted at 8.78%

		Baseline case	**5% Co-firing**
Electricity produced over analysis period		7 TWh	
Costs over analysis period	*Baseline investment for the plant*	*X*	
	Additional investment for co-firing	*0*	*500 k$*
	Fuel cost - Coal	*319 374 k$*	*297 341 k$*
	Fuel cost - Straw	*0*	*18 909 k$*
	O&M cost	*60 578 k$*	*61 131 k$*
	Tax	*35 085 k$*	*35 646 k$*
Sum of costs over analysis period, excluding the baseline investment		*415 036 k$*	*413 527 k$*
LCOE ($/kWh) excluding the baseline investment		*5.97 UScent/kWh*	*5.94 UScent/kWh*

Fuel cost saving

We calculated the fuel cost of Ninh Binh for two cases: baseline and co-firing. For baseline case, the coal type used in the plant has heating value of 21.55 MJ/kg; coal consumption is 420 000 ton/year. In case of co-firing the amount of straw needed to substitute 5% of heat is calculated at 53 362 ton/year with the heat value of coal at 11.7 MJ/kg. Straw required is estimated based on co-firing ratio. Straw price is estimated based on the price delivered at the field plus transportation price. The input for calculation is listed in Table 2. Referred to (Truong 2015) for detailed calculation of the straw required and straw price

Results (Table 4 and Table 5) shows that in case of co-firing, Ninh Binh power plant can substitute 28 975 ton of coal per year and save 337.000 USD/year of fuel expense. This is because Ninh Binh power plant is located in the province where straw supply is abundant. According to our calculation, Ninh Binh province could provide enough straw for co-firing at 5% rate in the plant. Moreover, Ninh Binh coal power plant is quite far from the coal mines (coal transport distance is 200 km) and Ninh Binh use higher rank coal, thus straw can compete with coal in term of price per unit of heat generated. Cumulative impact of co-firing to the fuel expense of the plant is presented in Table 4, in which Ninh Binh plant could save 3.15 million USD over 20 years of analysis.

Table 5. Result of fuel cost calculation for both cases

	Value
Coal price per 1 GJ heat generated	*3.80 $/GJ*
Straw price per 1 GJ heat generated	*3.27 $/GJ*
Fuel expense – baseline case	*34 432 k$/year*
Fuel expense – co-firing case	*34 095 k$/year*
Fuel cost saving	*337 k$/year*

Table 6. Result of fuel cost calculation for both cases

	Value
Coal price per 1 GJ heat generated	*3.80 $/GJ*
Straw price per 1 GJ heat generated	*3.27 $/GJ*
Fuel expense – baseline case	*34 432 k$/year*
Fuel expense – co-firing case	*34 095 k$/year*
Fuel cost saving	*337 k$/year*

Currently, coal for electricity generation in Vietnam is still subsidized. However, when coal price increase due to supply shortage, especially since Ninh Binh power plant uses domestic anthracite coal with higher quality and higher price and the reserve is depleting, co-firing could help to reduce fuel expense even more.

3.2. Impact to farmers and workers

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 straw price delivered at the field (USD/ton) and the straw yield (ton/ha). To collect rice straw, however, the farmers need to invest in straw winder and labor time. The price for straw winders varies from 4 000 to 18 000 USD. If the farmers do not 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. For the farmers in Ninh Binh province, their extra income if they sell rice straw to Ninh Binh power plant would be 172 USD per ha per year. Compare to the average annual income of farmers in Vietnam at 3 100 USD per ha per year, these extra income can add to 6.0 % of current income per ha of cultivation for farmers in Ninh Binh province. If we consider the total area of rice cultivation needed to supply enough straw to co-firing, the total benefit for farmers is 1.6 million USD.

Co-firing could create direct jobs from the establishment of straw supply chain and from co-firing operation and maintenance. Direct jobs created include straw collection, straw transportation and co-firing O&M. We assumed that straw is collected using straw winders with capacity of 6.5 ton/day. Straw is transported to the plant by 20-ton truck. Number of direct job created is estimated by total hour needed for the work to supply enough straw for co-firing in a year divided to total working hour per year of a full time equivalent job. Result is shown in Table 7.

Most of the jobs created are from straw collection work due to the scattered nature of this type of biomass. Beside, the collection method is not yet industrialized because the straw winders used are small and the paddy field in Vietnam is divided in small fractions. If straw collection process is improved, it could help to reduce the cost of biomass and make co-firing more profitable. However, in this case the job for straw collection will be less.

Table 7. Direct job created from co-firing

	Total working hour required	**Direct job created**
Straw collection	*64 932*	*42*
Straw transportation	*1 864*	*1*
Co-firing O&M	*4 497*	*3*
Total		*46*

The wage from job creation is then monetized by multiplying with the base salary for each type of job as stipulated in Decree no. 122/2015/ND-CP and Circular no. 17/2015/TT-BLDTBXH. The base salary is 144 USD/month for biomass collection and transportation, and 217 USD/month for operation and maintenance. Based on this assumption, the benefit of workers in co-firing is estimated at 82 000 USD/year.

3.3. Externalities

Positive externalities of co-firing rice straw include greenhouse gas emissions reduction (global impact) and cutting down the air pollutants emissions from in-field straw burning (local impact). Co-firing straw at 5% in Ninh Binh coal power plant help reduce 7 000 ton of CO_2 equivalence per year. This reduction is small, less than 1% of the current total emission of the plant, which is about 1 million USD per year. This is because the co-firing ratio is low. Beside, co-firing also emits greenhouse gases, although the emission factor of straw is lower than that of coal. With this amount of emission reduction, the benefit to climate is not significant. Also, if Vietnam have carbon market, this will not be a major benefit to the plant when do co-firing.

During operation, coal-fired power plant release air pollutants such as particulate matters (PM), SO_2 and NO_x. These substances have negative impacts to human health, especially people who live near the plants. Co-firing help to reduce these air pollutants because it contain much less S and N than coal (see Table 8). This is another positive externality of co-firing.

Table 8. Factors used in the estimation of externalities

	Emission factor[1, 2,3,4,5]			
	CO_2	*SO_2*	*PM10*	*NO_x*
Coal	*0.0988 kgCO_2e/MJ*	*11.5 kg/ton*	*26.1 kg/ton*	*18 kg/ton*
Straw	*0.0858 kgCO_2e/MJ*	*0.18 kg/ton*	*9.1 kg/ton*	*2.28 kg/ton*
Road transport	*0.062 kg/t CO_2e/t·km*			
Barge transport	*0.031 kg/t CO_2e/t·km*			
		Health damage cost[5] ($/ton of emitted pollutant)		
		SO_2	*PM10*	*NO_x*
		3 767	*5 883*	*286*

1(IPCC 2006), 2(Shafie, Mahlia, and Masjuki 2013), 3(McKinnon and Piecyk 2010), 4(Eastern Research Group 2011), 5(Hoang, Nguyen, and Le 2013), 6(Sakulniyomporn, Kubaha, and Chullabodhi 2011)

According to our calculation, SO_2, NO_x and PM emission is reduced significantly by co-firing straw (Table 9). Benefit from these reductions is monetarized using the health damage cost (Table 8). Health benefit is estimated at 1.35 million USD/year for co-firing case in Ninh Binh coal power plant. Of which the largest part comes from SO_2 emission reduction because Ninh Binh does not have desulfurization system.

Table 9. Results of estimation of air pollutant emission reduction and health benefit

	Baseline emission (ton/year)	**Co-firing emission (ton/year)**	**Emission reduction (ton/year)**	**Benefit (k$/year)**
SO_2	*4 830*	*4 506*	*324*	*1 219*
PM10	*88*	*86*	*2.2*	*13*
NO_x	*7 560*	*7 160*	*400*	*114*
Total				*1 346*

3.4. Policy discussion

To discuss policy implications, Figure 3 presents the overall cost-benefit overview of the co-firing cases. In the table, economic benefits are added up for the same number of years (twenty) as used for NPV calculation. We also used the same discount rate for simplicity. Our results suggest the following policy implications:

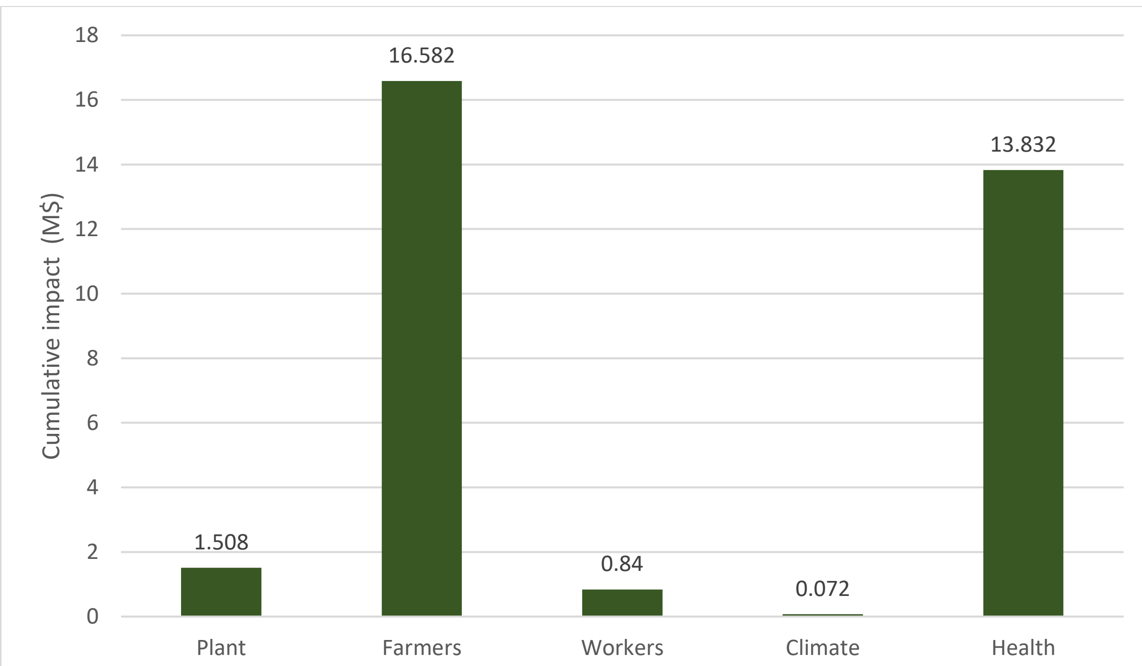

Figure 3. Cumulative impact of co-firing over 20 years

Co-firing provide economic benefit for the plant when it help to reduce fuel expense by substitute coal with local produced biomass. This is demonstrated by the higher NPV of co-firing case compared to 100% coal case and lower electricity generation cost.

The largest part of the benefit is extra income for farmers. Co-firing biomass is a way of giving value to agricultural "waste", it creates demand for agricultural products and the farmers are the first beneficiary. Our analysis suggests that co-firing rice straw is more an agricultural than an energy or environmental policy. This is similar to the bio-energy policy situations in many other countries in the world.

The positive impact to public health is significant. This is one of the externalities of co-firing. This number is and implication for policy makers when consider the supporting mechanism for co-firing. If there is an efficient way to share this benefit then the whole stakeholder could gain from doing co-firing. As we can see from the result, co-firing 5% of coal in Ninh Binh power plant could help society to avoid the cost of 13.8 million USD over 20 years for health care and treatment. Part of the avoided cost could be transfer to other group that might lose due to co-firing such as plant and coal mining workers and coal supplier to ensure all group could benefit from co-firing.

Co-firing creates direct jobs from biomass supply chain. Of which the most works are from straw collection. This reflect the nature of straw as well as other type of agricultural residue: scattered and seasonal.

Benefit from greenhouse gas emission reduction is the smallest part. This is assuming that the carbon value is 1 USD per ton of avoided CO_2 emission. We use that value because when we compare the carbon price and tax in many countries against their gross domestic product, we see that even the lowest income country in the list has much higher income than Vietnam. However, for the future when Vietnam establish its carbon market, this will be a positive impact to the economic viability of co-firing.

4. Conclusion

Co-firing biomass with coal is the technology to utilized available biomass resources to produce electricity at lower cost and higher efficiency than 100% dedicated biomass power generation technology. In the current context of Vietnam, co-firing is a cost-effective way to achieve the national target in increasing the share of biomass in power generation as stated in the latest Power Development Plan.

Direct co-firing is the most applied co-firing technology and the most suitable for Vietnam. It has low investment cost, simple to implement and can utilize the existing systems. Because Vietnam has potential in agricultural residues, this type of biomass should be considered first for co-firing. Biomass pellet is also a good choice with advantages over raw biomass; however, higher cost is the limitation of this type.

At first, co-firing should be demonstrated in the coal power plants that has favorable conditions for co-firing such as located in the rich biomass resource region where biomass could compete to coal in term of price, using imported coal or old, small plants that almost or already reach the end of their lifetime.

To optimize the benefit for all stakeholders involve in co-firing system, it is necessary to have policies that support co-firing such as cutting subsidy for coal, avoided cost tariff for electricity generated from biomass, carbon tax or other benefit sharing mechanisms.

In the case study of 5% straw co-firing in Ninh Binh coal power plant, we estimated the environmental and socio-economic costs and benefits of co-firing to different groups within the co-firing system in order to provide information to related stakeholder such as policy makers, investors, plant owners, farmers and workers when consider co-firing in Vietnam.

Results of the case study show that for Ninh Binh coal power plant, co-firing is feasible in term of economic even without considering supporting mechanisms and revenue from carbon price and selling ash. Co-firing also bring benefit to other group such as farmers and workers through providing extra income for farmers and creating jobs from straw supply chain. Moreover, co-firing has substantial positive externalities, especially the impact to public health through cutting down air pollution emission that is harmful to human.

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